Report of the Expert Panel on the Future of the Coded Wire Tag Program for Pacific Salmon

November 2005

Pacific Salmon Commission
Technical Report No. 18

The Pacific Salmon Commission is charged with the implementation of the Pacific Salmon Treaty, which was signed by Canada and the United States in 1985. The focus of the agreement are salmon stocks that originate in one country and are subject to interception by the other country. The objectives of the Treaty are to 1) conserve the five species of Pacific salmon in order to achieve optimum production, and 2) to divide the harvests so each country reaps the benefits of its investment in salmon management.

Technical Reports of the Pacific Salmon Commission present results of completed or ongoing investigations carried out by the Pacific Salmon Commission that are deemed of sufficient interest to be made available to the scientific community and the public.

The contents of these reports may be reprinted, and reference to the source will be appreciated.

Pacific Salmon Commission
600 - 1155 Robson Street
Vancouver, B.C.
V6E 1B5
(604) 684-8081

Pacific Salmon Commission
Technical Report No. 18

Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon *

November, 2005

* Includes Attachment One: Agency Responses to the Report of the Expert Panel on the Future of the Coded Wire Tag Program for Pacific Salmon

Correct citation for this publication:

Expert Panel on the Future of the Coded Wire Tag Program for Pacific Salmon. 2005. Report. Pacific Salmon Comm. Tech. Rep. No. 18: 230 p.

EXPERT PANEL MEMBERS

David G. Hankin (Chair)
Professor and Chair
Dept. of Fisheries Biology
Humboldt State University
Arcata, CA 95521

John H. Clark
Chief Fisheries Scientist
Commercial Fisheries Division
Alaska Dept. of Fish and Game
Juneau, Alaska, 99802-5526

Richard B. Deriso
Chief Scientist for Tuna-Billfish Program
Inter-American Tropical Tuna Commission
Scripps Institution of Oceanography
La Jolla, CA 92093-0203

John Carlos Garza
Supervisory Research Geneticist
Santa Cruz Laboratory
NOAA SW Fisheries Science Center
Santa Cruz, CA 95060

Gary S. Morishima
CEO
MORI-ko, LLC
Mercer Island, WA 98040

Brian E. Riddell
Research Scientist
Pacific Biological Station
Science Branch
Fisheries & Oceans Canada
Nanaimo, BC V9T 6N7

Carl Schwarz
Professor
Dept. of Statistics and Actuarial Science
Simon Fraser University
Burnaby, BC, V5A 1S6

James B. Scott
Chief Fish Scientist
Washington Dept. of Fish and Wildlife
Olympia, WA 98501

RECEIVED
PACIFIC SALMON

PSC CHINOOK TECHNICAL COMMITTEE

11 October, 1991

Patrick S. Chamut
Director General, Pacific Region
Dept. Fisheries and Oceans
555 W. Hastings St.
Vancouver, B.C. V6B 5G3

Joseph R. Blum
Director
Washington Dept. of Fisheries
115 General Administration Building
Olympia, WA 98504

Dear Mr. Chamut and Mr. Blum:

The removal of adipose fins to distinguish between hatchery and wild production has been proposed by several participants in the Salmon Summit and Northwest Power Planning Council and is being reviewed by the PSMFC Mark Committee. Since the inception of the coded-wire-tag (CWT) program, Canadian and U.S. fisheries agencies have, by mutual agreement, removed adipose fins from coho and chinook exclusively to identify coded-wire-tagged fish.

The CWT program is an integral part of the coastwide assessment program for chinook and coho salmon stocks and fisheries. The necessity of maintaining a viable, coastwide CWT program was recognized in the Memorandum of Understanding, Section B (Data Sharing) accompanying the Pacific Salmon Treaty: **"The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations."**

The Chinook Technical Committee (CTC) discussed the proposal and is strongly opposed to the use of adipose clips to mass-mark hatchery fish. This practice would render the CWT program nearly useless as a management tool. The presence of large numbers of adipose-clipped fish without CWT's may make it infeasible to sample and recover adequate numbers of CWT's for reliable statistical analysis.

The maintenance of a viable CWT program is essential. No other data and/or methods exist that are currently capable of providing the information required to evaluate the effectiveness of chinook and coho fishery management actions undertaken by the PSC. The CWT program provides information on stock exploitation patterns and rates, and survivals. It is required for evaluating the effectiveness of management actions undertaken by the Pacific Salmon Commission (PSC) to rebuild chinook stocks. If adipose clips are used on untagged hatchery fish, coastwide assessments of the chinook rebuilding program simply cannot be completed.

Several substantial management problems would result if the adipose fins were to be removed from large numbers of untagged hatchery-reared chinook and coho. Some of these are listed here.

(1) CWT recovery data could no longer be utilized to evaluate fishery impacts on wild populations. Examples include: (a) if fish with adipose-clips are selectively harvested, catch and incidental fishing mortalities would differ for tagged and untagged fish; (b) it would be nearly impossible to collect adequate CWT recovery data to permit analysis of wild fish tagging experiments involving relatively small releases.

(2) The ability to estimate interceptions and determine the degree to which allocation objectives and obligations are achieved would be seriously compromised.

(3) If implemented, groups and agencies involved in the coastwide tagging program is highly uncertain. For example, the selective harvest of clipped fish may lead an agency to discontinue clipping (and tagging) fish.

(4) Un-clipped populations would be subjected to increased incidental fishing mortalities of unknown magnitude.

(5) Handling and fin clipping larger numbers of hatchery fish will increase mortality and subsequently reduce their abundance in ocean fisheries. In fisheries with catch ceilings, this change in stock composition will increase exploitation on the natural stocks.

(6) A variety of scientific experiments that depend on CWT's would be disrupted.

(7) Management procedures (e g. run-size forecasting, in-season abundance estimation) that depend on CWT's would have to be eliminated, revised, or replaced.

We urge the PSC Commissioners to take a strong stand against the use of adipose fins to mass-mark hatchery-reared chinook and coho. Other methods of mass-marking hatchery fish are available if necessary, but the removal of the adipose fin from untagged fish would destroy a long-standing program of international cooperation in the use of the CWT as an important management tool.

Jim Scott
U.S. CTC Co-Chair

Norma Sands
U.S. CTC Co-Chair

Brian Riddell
Canada CTC Co-Chair

cc: Chinook Technical Committee
Coho Technical Committee
Data Sharing Committee
PSC Commissioners

PREFACE

In early 2004, the Pacific Salmon Commission (PSC) convened a panel of experts in various fields of fisheries science to examine the current status of the coded wire tag (CWT) system and to develop findings and recommendations concerning the future of the CWT system in PSC management. Expert Panel members were selected by Commissioners of the PSC and the PSC's Committee on Scientific Cooperation (CSC). One CSC member (Hankin) was asked to serve as Chair of the Expert Panel. Initial activities of Panel members included review of a selected set of background papers (see http://www.psc.org/info_codedwiretagreview.htm) and attendance at a four day workshop held from 7-10 June 2004 in Seattle, WA. The first three days of this workshop consisted of invited presentations on three themes:

1. The advice required by agencies and the PSC, which currently depend on data provided by the CWT program;
2. A technical review of the current CWT program, including the issues surrounding the adequacy of CWT data, current levels of uncertainty, and modifications that would address the concerns identified, as well as the costs of the program; and
3. A review and evaluation of alternative technologies that might enhance or replace all or part of the CWT program.

The fourth day of the workshop was devoted to internal Panel discussions of materials, presentations and issues relevant to fulfilling its charge.

In announcing the workshop, the PSC charged the Expert Panel with addressing a very specific issue of concern (estimation of age- and fishery-specific mortality rates of salmon from natural stocks in the context of mass marking and mark-selective fisheries) but at the same time charged the Panel with exploring a much broader set of concerns:

> *The workshop is intended to examine limitations of the CWT program and to evaluate the capacity of alternative technologies to provide data to improve assessment of Chinook and coho salmon. While the charge for the workshop is from the Pacific Salmon Commission and concern for our ability to estimate age and stock specific mortality rates by fishery, these data have many other uses (e.g., monitoring compliance with jeopardy standards established pursuant to the U.S. Endangered Species Act and for hatchery-specific experiments). Also, data collected using alternative technologies (such as genetic information, otolith marks, or other tags) may provide opportunities to augment a modified CWT-based system.*

Panel efforts to address the specific issue of concern identified above inexorably led us to engage in a much broader review of a large number of fundamental issues that concern management of salmon fisheries by the Pacific Salmon Commission. The findings and recommendations that we present in this report address fundamental assumptions or concerns that we identified through our review and which, in general, concern the basic infrastructure that may be needed to support future salmon management by the PSC.

Following the workshop, individual Panel members were asked to prepare specific sections of the Panel's report and to respond to a preliminary set of findings. The full Panel met again in Seattle on 18 October 2004 to discuss a rough version of a draft report. Following this meeting, a second draft report focusing primarily on Findings and Recommendations was developed and was the

subject of a second full Panel meeting in Vancouver, BC on 14-15 January 2005. Preparation of a draft final report was the subject of a third full Panel meeting in Seattle on 13-14 May 2005.

In late June 2005, the draft final report was revised and sent out for peer review to Dr. Terry Quinn (population dynamics and sampling theory), University of Alaska, Juneau, AK; Dr. John Skalski (statistics), University of Washington, Seattle, WA; Dr. Don Campton (fish genetics), US Fish and Wildlife Service, Abernathy, WA; Dr. Carl Walters (population dynamics and fishery management theory), University of British Columbia, and Dr. Peter Lawson (fishery management), NOAA Fisheries, Newport, OR. Following receipt of peer review comments, Expert Panel members circulated their responses to these comments and determined how best to respond. The Expert Panel's final report responds to peer review comments and will be formally submitted to the PSC in early November 2005. It is anticipated that the PSC will distribute the report to fishery management agencies for review for a limited period of time. The Expert Panel may be requested to respond to agency comments.

Some peer reviewers suggested that the value of the Expert Panel's report would be enhanced if it were to provide detailed cost comparisons of expanded CWT tagging and recovery programs and/or various alternative technologies that might be used to supplement or replace the existing CWT system. Although we agree with these peer reviewers that such cost comparisons would be a useful addition to our report, we believe that developing such cost comparisons is well beyond the scope of activities that can be reasonably expected of Panel members. We believe that appropriate PSC technical committees should be charged with developing cost comparisons for various alternative strategies after release and consideration of this report.

This document constitutes our final report and consists of four main parts: (1) An explanatory background section that sets the context for our Panel's task; (2) an Executive Summary of our principal Findings and Recommendations, including a brief series of proposed Implementation Steps; (3) a thorough justification and rationale for those findings and recommendations for which we believe a justification or rationale is necessary and/or important; and (4) a series of Appendices that provide additional supporting information or analyses. We have devoted substantial editorial attention to parts (1) and (2) of our report; these sections of our report are likely to be examined most carefully by most readers. We recognize that parts (3) and (4) of our report would benefit from similar efforts to ensure editorial consistency in presentation, but we do not believe that the modest incremental improvements in our report that might result would justify delay in release of our report. We believe that it is important to release our report now.

Panel members extend a special thanks to the Northwest Indian Fisheries Commission (NWIFC) for funding the extensive and invaluable technical assistance that we have received from Marianna Alexandersdottir, biometrician for NWIFC. We also thank PSC staff, in particular Don Kowal, Executive Secretary, and Vicki Ryall, Meeting Planner, for their assistance in coordinating the logistics of Expert Panel meetings.

GLOSSARY

All terms that are specific to PSC management are indicated as (PSC).

AABM	Aggregate Abundance Based Management (PSC)
Ad	Adipose fin clip
Ad+CWT	Adipose fin clip with a coded wire tag
ASFEC	Ad-Hoc Selective Fisheries Evaluation Committee (PSC)
CoTC	Coho Technical Committee (PSC)
CSC	Committee on Scientific Cooperation (PSC)
CTC	Chinook Technical Committee (PSC)
CWT	Coded wire tag
CV	Coefficient of Variation
DIT	Double Index Tagging
ESA	U.S. Endangered Species Act
ETD	Electronic tag detection
FPG	Full parental genotyping
GSI	Genetic Stock Identification
ISBM	Individual Stock Based Management (PSC)
MM	Mass Marking
NPAFC	North Pacific Anadramous Fish Commission
MSF	Mark-Selective Fisheries
NSF	Non-Selective Fisheries
NWIFC	Northwest Indian Fisheries Commission
PIT	Passive Integrated Transponder tag
PSC	Pacific Salmon Commission
PSE	Percent standard error
PSMFC	Pacific States Marine Fisheries Commission
PST	Pacific Salmon Treaty
RFID	Radio Frequency Identification tag
RMIS	PSMFC CWT database – Regional Mark Information System
SFEC	Selective Fishery Evaluation Committee (PSC)
SIT	Single Index Tagging
SNP	Single nucleotide polymorphisms

TABLE OF CONTENTS

PART I. BACKGROUND INFORMATION 1
History of Coded Wire Tagging Programs 1
CWTs and the Pacific Salmon Treaty 5
Emerging Problems with the CWT System 7
Increasing Complexity of Fisheries 8
Mass Marking and Mark-Selective Fishing 9
The CWT Workshop 16
PART II. EXECUTIVE SUMMARY 21
MAJOR FINDINGS 21
The Coded Wire Tag Recovery System 21
Importance of the CWT Tag Recovery System 22
Problems with the Existing CWT Tag Recovery System 22
Issues Raised by Mass Marking & Mark-Selective Fisheries 23
Existing and Future Technologies that Might Complement or Replace the CWT System 25
MAJOR RECOMMENDATIONS 28
Correct Current Deficiencies in CWT System: 28
Respond to Mass Marking and Mark-Selective Fisheries 29
Develop a Coordinated Research & Implementation Plan 31
Consider New Management Paradigms 32
IMPLEMENTATION STEPS 33
CITATIONS 37
PART III. JUSTIFICATIONS AND RATIONALE FOR EXPERT PANEL FINDINGS AND RECOMMENDATIONS 39
MAJOR FINDINGS 39
MAJOR RECOMMENDATIONS 96
PART IV. APPENDICES 134
APPENDIX A. Proposed Scheme for Estimation of Total Age-Specific Non-Catch Mortalities to Unmarked Chinook Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries. 135
APPENDIX B. Can Mark-Selective Fishery Mortality Rates be Estimated from DIT Studies when Movement and/or Segregation occurs? Partial Estimates from DIT Studies. 146
APPENDIX C. Proposed Application of GSI and Indicator Stock Data 150
APPENDIX D. Current Status of Pacific Salmon Genetic Databases. 156
APPENDIX E. Chinook Salmon CWT indicator stock releases. 163
APPENDIX F. Alternative Schemes for Estimating Total Age-Specific Non-landed Mortalities to Unmarked Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries 166
APPENDIX G. Increasing Fishery Complexity Leads to Increased Uncertainty in Estimated Fishery-Specific Exploitation Rates. 190
APPENDIX H. Comparison of Sampling Requirements for CWT and Genetic Based Methods. 198
APPENDIX I. Curriculum Vitae of Expert Panel Members. 208

LIST OF TABLES

Table 1.	Required Use of the Adipose Fin Mark with the CWT.	12
Table 2.	Fishery Sampling Methods for Coded Wire Tagged Coho	17
Table 3.	Fishery Sampling Methods for Coded Wire Tagged Chinook	18
Table 4.	Estimation methods for unmarked mortalities in MSFs at varying MSF magnitudes.	30
Table 5.	Sampling statistics for fisheries exploiting coho salmon in Washington State (except Columbia River) for 1998-2000.	42
Table 6.	Average number of tags recovered per year (Tags) and the number estimated (Exp) from these recoveries for the Green-Duwamish Chinook salmon indicator tag group for brood years 1971-1998.	48
Table 7.	Statistics collected for the Brownie model	108
Table 8.	Expected recoveries using the formulation of Brownie et al (1985).	108
Table 9.	Expected recoveries when survival is to be partitioned into various components.	109
Table 10.	Conceptual approach for linking marking, tagging, and analytical methods to the anticipated intensity of selective fisheries.	117
Table 11.	Four scenarios describing the combination of a mass mark, a uniquely marked or tagged indicator stock, and the estimator for the mortality of unmarked fish of the indicator stock in a MSF.	119

LIST OF FIGURES

Figure 1. Longitudinal section through the head of a juvenile salmonid showing the correct placement of a coded wire tag in the nasal cartilage. 1

Figure 2. Fishery time step strata for each CTC exploitation rate indicator stock used in Chinook Technical committee model at different levels of resolution. 10

Figure 3. Conceptual Schematic of DIT Releases and Recoveries in non-selective fisheries (NSF), mark-selective fisheries (MSF) and freshwater escapement. 14

Figure 4. AutoFish System from Northwest Marine Technology is capable of automated removal of the adipose fin and/or insertion of a CWT. 16

Figure 5. Estimates of exploitation rates on Robertson Creek Chinook salmon for brood years 1973-1998 (Taken from CTC 2004). 44

Figure 6. Estimates of marine survival index for Robertson Creek Chinook salmon brood years 1973-1998 45

Figure 7. Number of tagged fish in fisheries and in escapement and percent of total in escapement for Soos Creek (Green-Duwamish hatchery) Chinook salmon for brood years 1971-1998. 45

Figure 8. Estimated PSE of tagged harvest or escapement as a function of number of tags recovered and the sample rate. 47

Figure 9. Total harvest rates and marine survival rates for Hatchery (Big Qualicum, Quinsam, and Chilliwack) and 2 wild (Black Creek and Salmon River) coho indicator stocks in the Strait of Georgia, B.C. 54

Figure 10. Directed graphical model depicting Hankin's (2004, Appendix A) incidental mortality estimation using double index tagging 54

Figure 11. Management targets with increasing uncertainty 115

LIST OF APPENDIX TABLES

Table C1. Total CWT recoveries from the Salmon River Hatchery indicator stock, 1997 –2002 catch years, by fishery, terminal catch, terminal escapement, and age composition of SEAK fishery recoveries for brood years in the 2001 and 2002 calendar year fishery. 153

Table C2. Estimated mature CWT recoveries from Salmon River Hatchery indicator stock, 1997 –2002 calendar years, by fishery, terminal catch, terminal escapement, exploitation rate for SEAK troll fisheries, and ratio of mature catch to terminal run recoveries for broods in the 2001 and 2002 calendar year fisheries. 154

Table C3. Estimated NOC chinook salmon terminal run in 2001 based on Salmon River Hatchery CWT recoveries and GSI catch estimates of NOC chinook salmon in the SEAK troll fishery (July + fall). 155

Table F1. Summary of Advantages and Disadvantages of SIT+ System 168

Table G1. Distribution of PSE for estimates of fishery distribution (mortality in fishery over total fishery mortalities) for Upriver Brights for three configuration of fishery-time steps used in CTC model for CWT data from 1975-1984. 191

Table G2. Distribution of PSE for estimates of fishery distribution (mortality in fishery over total fishery mortalities) for Upriver Brights for three configuration of fishery-time steps used in CTC model for CWT data from 1989-1998. 195

Table G3. Number and percent of fishery-time step strata with 0, 10 or fewer and more than 10 tags recovered for Upriver Brights for two groups of broods, 1975-1984 and 1989-1998. 197

Table H1. Allocation to stock using assignment matrix used in simulation and calculation of error and estimated relative bias in percent due to misallocation to stock. 200

Table H2. Mean and SD for 500 iterations estimating number by stock and age for three scenarios and results of test of null hypothesis that there is no difference between the mean of the estimate and the true value. 204

LIST OF APPENDIX FIGURES

Figure B1. Schematic of simple migration model for chinook. Adopted from SFEC (2002). 146
Figure F1. Simulated encounters of DIT-U and DIT-M fish 187
Figure F2. Box and whiskers plot of encounter ratios of DIT-U:DIT-M fish at various target harvest rates for removal of DIT-M fish. 188
Figure G3. Percent of total tagged release that is estimated to be landed harvest in fisheries for brood years 1975-1998 for Upriver Bright chinook salmon. 194
Figure G1. Distribution of percent fishery mortalities for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) current or 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year. 192
Figure G2. Distribution of percent standard error (PSE) for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year 193
Figure G3. Percent of total tagged release that is estimated to be landed harvest in fisheries for brood years 1975-1998 for Upriver Bright chinook salmon. 194
Figure G4. Distribution of percent standard error (PSE) vs number of tagged recoveries for fishery percent of total for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year. 196
Figure H1. Average of error in 500 simulations (=bias) with 95% confidence interval for stock 1 with and without assignment error. 201

PART I. BACKGROUND INFORMATION

History of Coded Wire Tagging Programs

The coded wire tag (CWT) was introduced in the 1970s and has provided unparalleled information about ocean distribution patterns and fishery impacts for numerous stocks of salmon along the west coast of the US. Prior to the advent of the CWT, researchers had relied principally on ocean tagging of adults or fin clipping of juveniles to gather information about harvest patterns of salmon. Adult tagging provided information that confirmed that ocean fisheries were harvesting complex mixtures of stocks, but could not provide information required to determine exploitation patterns of individual stocks; tag recovery programs were incomplete due to the numerous fisheries and stream destinations involved. Fin-clip studies of juveniles provided some information on patterns of exploitation of a few stocks, but marking, fishery sampling and reporting of recoveries were not coordinated across geographic and political boundaries. Because of limitations in the number of fin-clip combinations available, researchers could conduct experiments on at most 15-20 groups of fish at a time. With hundreds or even thousands of stocks of interest, fin clipping technology provided little hope of providing the stock- and fishery-specific information desired by managers.

The CWT is a small piece of magnetized wire (0.25 x 1.1 mm) which is implanted in the nasal cartilage of juvenile salmonids (Figure 1).

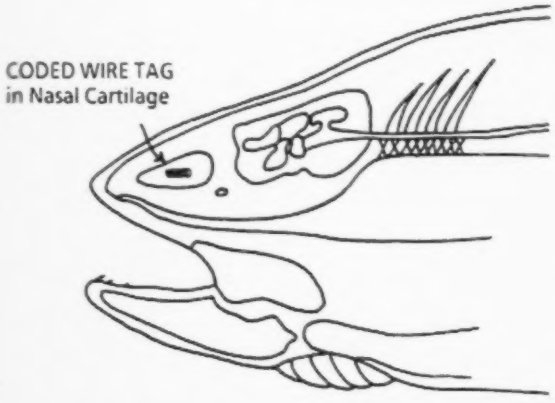
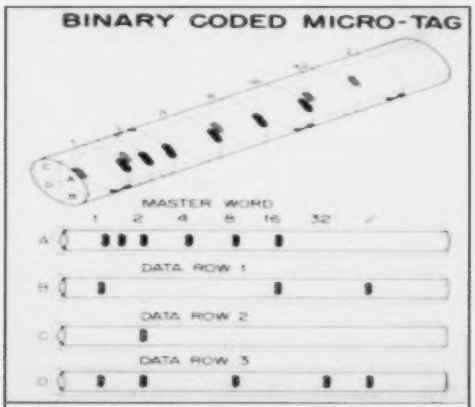


FIGURE 1.—Longitudinal section through the head of a juvenile salmonid showing the correct placement of a coded wire tag in the nasal cartilage. (After Koerner 1977.)

Each piece of wire contains a code that uniquely identifies an individual group of fish (batch coding). Original color codes were replaced in 1971 by a binary coding system implemented through notches etched in the wire. The binary CWTs eliminated errors in decoding colored tags and expanded the number of codes to over 250,000. Since about 1998, CWTs have been available in a decimal printed format which virtually eliminates reading errors. The very large number of available unique codes has allowed all experimental groups to be identified accurately regardless of place or time of recovery.



Example of binary code used on coded wire tags. Notice the code is present on four sides of the tag.

The advantages of CWTs over fin clipping quickly became obvious and the special characteristics of Pacific salmon made the CWT ideally suited for life history research. Because Pacific salmon are semelparous, the entire fate of a marked cohort is *a priori* certain to be completed over a relatively short period of time (3-4 yr for coho, no more than 7 yr for chinook). Strong homing fidelity enables the freshwater search for CWTs in adult fish escaping marine harvest to be confined to well-defined geographic areas, usually near release sites. Because CWTs can be inserted into juvenile fish prior to ocean migration, the technology provides a means to track the fate of specific groups of salmon from release through to maturity. The CWT's unambiguous identification of the specific release group from which a fish originated was essential for evaluation of individual release experiments typically carried out with hatchery fish. All experimental groups could be treated identically during the tagging process, distinguished only by a coded wire tag number, thereby eliminating confounding effects that had been presented in many earlier fin clipping studies when contrasting groups might have been released with, say, a left ventral fin clip or an anal fin clip.

Because CWTs are not externally visible, an external mark was needed to indicate that a fish contained a CWT. By agreement of management agencies in 1977, the adipose fin clip[1] (adipose mark - Ad) was sequestered (reserved) for fish that also received a CWT (Ad+CWT). Fish could

[1] The functional purpose of the adipose fin is unclear. Once thought to be a vestigal fin that could be removed without effect, recent research suggests that the adipose may control vortices enveloping the caudal fin during swimming or function as a turbulence sensor. The authors suggested that: *"the current widespread practice in fisheries of removing the adipose fin as a marking technique may have significant biological costs."* Reimchen and Temple (2004).

then be inspected visually and snouts removed from those with missing adipose fins (i.e., from Ad+CWT fish). In the late 1970s, management agencies also agreed to institute catch sampling and reporting protocols to facilitate sharing of data on where and when fish from individual release groups were harvested. CWT codes are issued by and reported to a central location so as to avoid duplication of codes and maintain unambiguous assignment of recoveries to specific release groups. The Pacific States Marine Fisheries Commission (PSMFC) has continued to provide the lead CWT data coordination role and maintains the RMIS database (Johnson 2004).

CWTs are recovered coast-wide with agencies generally attempting to sample at least 20% of the ocean catch. Freshwater recovery programs are less standardized. Returns of Ad+CWT fish to hatcheries are usually sampled at a 100% rate, but sampling rates for stray escapement are highly variable and there is generally substantial uncertainty in estimates of stray (non-hatchery) escapement to natural spawning grounds for hatchery CWT groups. (In some systems, a very large proportion of returning hatchery fish may fail to return to hatcheries.) Nevertheless, since the late 1970s, CWT tag recovery data have provided an essential technical basis for chinook and coho salmon management.

Through this coordinated, coast-wide system, CWT tag recovery data have enabled fisheries scientists to determine exploitation patterns for individual groups of fish, ended debate over "who was catching whose fish", and have assisted decision-making required to conserve the resource. In the mid 1980s, stock and fishery assessment methods based on CWT tag recovery data provided the means to define exploitation patterns for individual stocks. The high levels of exploitation in fisheries in the mid 1980s resulted in sufficient CWT recoveries to provide statistically reliable data. Cohort analysis methods[2] applied to CWT recovery data permitted estimation of age- and fishery-specific exploitation rates, age-specific maturation rates, survival from release to age 2, and total mortality. These methods quantified and characterized the timing and location of fishery impacts for the entire migratory range and life cycle of individual stocks. Exploitation patterns of natural stocks were assumed to be the same as those determined for CWT release groups of hatchery fish that had similar brood stock origin, similar maturation schedule, and that were reared and released in a manner believed similar to natural stocks.

In the mid 1980s, the integration of CWT-based cohort analysis into simulation models provided the primary means to inform decisions regarding the degree to which fishery impacts needed to be reduced to constrain exploitation rates to levels appropriate for the status and productivity of individual stocks. These models proved instrumental in enabling the U.S. and Canada to reach agreement on a coast-wide chinook rebuilding program that became a cornerstone for the 1985 Pacific Salmon Treaty (PST).

In addition to cohort analysis and simulation modeling, the CWT was being widely employed for evaluation of hatchery production, identification of migration and exploitation patterns, estimating and forecasting abundance, and in-season regulation of fisheries (Cooney 2004;

---

[2] Cohort analysis involves the backwards reconstruction of a population, beginning with estimated spawning escapements of the oldest aged fish, estimated fishery recoveries, and assumptions regarding natural mortality rates. The capacity to reconstruct the complete demographic history of discrete groups of fish from CWT recoveries is vital to the capacity to perform cohort analyses on Pacific salmon. For a description of general theory, methods, and data requirements, see CTC 1988 and Morishima and Alexandersdottir (2004).

Johnson 2004). Particularly for chinook (*Oncorhynchus tshawytscha*)[3] and coho (*O. kisutch*)[4] salmon, the CWT quickly became indispensable to fishery managers. Recognizing that no other data or methods existed which were capable of providing the information to evaluate the effectiveness of the agreements reached under the PST, the United States and Canada entered into a special Memorandum of Understanding when signing the PST: *"The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations."* (Section B, data sharing).

Today, millions of dollars are expended annually to tag and recover CWTs. Johnson (2004) reported that some 54 state, federal, tribal, and private entities in the USA and Canada conduct CWT experiments involving some 1200 new codes annually. Over 50 million juvenile salmon and steelhead are now tagged annually[5] at a total cost in excess of U.S. $7.5 million annually. Approximately 275,000 CWTs are recovered each year in commercial and recreational fisheries and in spawning escapements, at an additional annual cost of U.S.$12-13 million. CWTs are being increasingly employed in conjunction with other stock identification technologies such as genetic markers, scale pattern, and otolith banding to provide a better analysis of salmonid population dynamics (Johnson 2004).

For three decades, the CWT has provided a practical, efficient, and cost-effective means for stock- and fishery-specific assessment. Coordinated, coast-wide sampling and reporting systems facilitate sharing of information on CWT releases and recoveries via internet access. Recoveries of CWTs are expanded for catch sampling rates and are reported, usually within a few months of harvest, by time and fishery strata. CWT release records provide information on location and timing of release, study purpose, stock (hatchery or natural), age at recovery, size at tagging and size at recovery. Standardized methods for CWT data analysis reduce opportunities for misinterpretation. The capacity to conveniently analyze experimental results for individual CWT release groups in a timely manner has proven invaluable for salmon fishery management, research, and monitoring (e.g., estimation of hatchery contributions to catch, abundance forecasting, identify variations and trends in marine survival over time, determine the scale of stock-dependent differences). The Pacific Salmon Commission's (PSC) Ad-Hoc Selective Fisheries evaluation Committee (ASFEC, 1995) summarized the main reasons why all salmon fishery management agencies in the Pacific Northwest rely upon the CWT:

1. *the CWT program includes fully integrated tagging, sampling, and recovery operations along the entire west coast of North America;*

2. *the CWT provides sufficient resolution for stock-specific assessments; and*

---

[3] Chinook are the largest and longest lived species of Pacific salmon and tend to spawn in larger river systems. More than a thousand spawning populations (stocks) of this species are found in rivers along the eastern Pacific (several distinct spawning populations - often characterized by river entry timing – e.g., spring, summer, fall, winter - defined by a combination of timing and physical location may be found in a single river system). Individual stocks can migrate over thousands of miles and be exploited over an extended period of time at various stages of maturity.

[4] Several thousand coho stocks are believed to exist in rivers along the eastern Pacific. This species is characterized by an extended period of freshwater rearing (1 to 2 years) followed by approximately 18 months of rearing in marine areas prior to returning to the rivers to spawn. From Southern British Columbia southward, coho are predominantly produced on a three year life cycle (one year freshwater). In more northerly areas, coho with four year life cycles are common (two years freshwater). Coho are harvested predominantly during the last few months of marine residence. Most coho return to their rivers of origin in late summer and fall, although some stocks are known to have very early or late timing. Coho tend to be distributed over a much smaller range than Chinook.

[5] Chinook salmon tagging levels are the highest (~39 million), followed by coho salmon (~9-10 million).

3. *the CWT is the only stock identification technique for which a historical record (generally back to the mid 1970s) of stock-specific assessments may be computed.*

No other practical mark-recovery system has yet been devised that is capable of providing this level of detail in such a timely fashion. The historic success of the CWT program has been in no small part due to the high level of coordination and cooperation among the coastal states and British Columbia and to the consistency of CWT tagging and recovery efforts across the many political jurisdictions. Despite the emergence of other stock identification technologies, including various genetic methods and otolith thermal marking, the CWT tag recovery program remains the only method currently available for estimating and monitoring fishery impacts on individual stocks of coho and chinook salmon for implementation of fishing agreements under the Pacific Salmon Treaty (PST).

CWTs and the Pacific Salmon Treaty

The pivotal role that analysis of CWT data and modeling played in enabling the United States and Canada to reach agreement on the PST in 1985 has already been described. The integration of CWT-based cohort analysis into simulation models continues to inform the decisions of the PSC of the degree to which fishery impacts need to be constrained to levels appropriate for the status and productivity of individual stocks.

For chinook and coho salmon, the focus of the PSC's agreements is on management of natural stocks that are harvested by the fisheries of both countries. These species are impacted by a variety of commercial and recreational marine interception fisheries and terminal freshwater fisheries throughout the migratory ranges of individual stocks. There are few tagging programs on natural stocks, however, and there are therefore few CWT tag recovery data to permit direct estimation of exploitation rates for naturally spawning populations of coho and chinook salmon. Capture and tagging of juveniles and enumeration of returning adults from natural stocks are logistically challenging and costly. Consequently, inferences concerning exploitation impacts on natural stocks are drawn from surrogate groups of artificially propagated and tagged hatchery fish. PSC fishing regimes depend on selection of a system of hatchery stock indicators for natural stocks, based on origin of the spawning stock and rearing/release strategies (see Appendix E). Estimates generated from cohort reconstruction of the selected CWT hatchery indicator stock groups (e.g., maturation rates, age- and fishery-specific exploitation rates) are assumed to apply to associated naturally spawning populations: selected CWT release groups are assumed to be subject to the same fishing patterns as the naturally spawning stocks they are intended to represent. CWT-based estimates of age- and fishery-specific exploitation rates of hatchery stock indicators are therefore used as surrogate measures of the impacts of fisheries on naturally spawning populations.

The Parties to the PST have established a system of CWT indicator stocks (predominantly hatchery stocks that are consistently tagged over time) to provide data to monitor impacts of PST agreements on fishing regimes. PSC agreements for chinook and coho depend critically upon estimates of age- and fishery-specific exploitation rates for individual stocks (Morishima 2004).

For chinook, the allowable catch levels in certain highly mixed stock fisheries (Aggregate Abundance Based Management, or AABM, fisheries) are determined through the use of an abundance index derived by applying age- and stock-specific exploitation rates to projections of stock abundance at age. These exploitation rates are derived from analysis of historical CWT data and applied through simulation models on a stock- and age-specific basis. AABM fisheries actually consist of aggregations of fisheries that harvest individual stock- and age-specific components at different rates. Although AABM fishery regimes were initially based on landed catch, the Parties agreed to move to regimes based on total mortality impacts (i.e., including non-landed catch-and-release mortalities) as soon as practicable. Information on stock-age-fishery-specific exploitation rates continues to be required to set annual catch targets and monitor impacts of AABM fisheries.

For chinook, PSC fisheries that are not considered part of AABM fishery aggregates are managed to constrain total mortality on individual natural stocks that are not achieving their spawning escapement goals. These are termed Individual Stock Based Management (ISBM) fisheries. Each Party is required to reduce impacts of its ISBM fisheries by agreed amounts relative to levels observed during a selected base period. Compliance with ISBM provisions is monitored through use of a formula that requires stock-age-fishery-specific estimates of exploitation rates for depressed natural stocks. For both AABM and ISBM regimes, evaluation depends heavily on the availability of data to support cohort analysis on individual indicator stocks that are selected to represent natural stocks of interest.

For coho, PSC regimes for naturally spawning management units originating in Southern British Columbia and Washington are based on agreements to constrain exploitation rates to negotiated levels. These management units are comprised of aggregations of hatchery and natural stocks. Each Party is required to constrain the fisheries within its jurisdiction so as not to exceed exploitation rates on management units. Those constraints are determined by negotiated agreement, based on categorical (low, moderate, or abundant) conservation status. The application of CWT-based cohort analysis and pre-season abundance forecasts within a bilateral fishery planning tool provides the Parties with a consistent and convenient means to evaluate proposed regulations for a given season in relation to negotiated agreements. Monitoring occurs largely through cohort analysis of CWT data for selected indicator stocks. The bilateral allocation of total mortality impacts requires stock-fishery specific exploitation rates on individual stocks which are the components of management units.

Current PSC fishery regimes for chinook and coho are inextricably linked to the CWT system. In his introductory remarks to the CWT Workshop, Rutter (2004) described this relationship as follows:

> *"Over the past thirty years or so we have constructed an elaborate and interdependent fishery management and stock assessment scheme that is heavily reliant upon data comprised of CWT recoveries. Billions of CWTs have been placed in salmon over the years, mostly in chinook and coho salmon. And, through an elaborate, coast-wide sampling program that sifts through escapements and catch in fisheries far and wide, millions of CWTs have been recovered. Over time, we have accumulated what surely must be one of the most*

extensive fishery management data sets found anywhere in the world. This data set is analyzed and manipulated with increasingly complex models and algorithms; the results of these analyses provide the backbone of our system for managing chinook and coho salmon fisheries coast-wide. The data and models have become so inextricably intertwined with our regulatory and management regimes that I sometimes wonder whether the models inform our decisions, or whether some of our decisions are made to conform to the models."

Emerging Problems with the CWT System

Increased dependence on CWT tag recovery data has resulted in increased concern regarding the quality of CWT recovery data and inferences that have been drawn from analyses of these data. A key assumption underlying PSC regimes is that the selected hatchery indicator stocks are representative of their associated natural stocks. Because of the difficulty of tagging and recovering sufficient numbers of naturally produced fish, direct validation of this assumption through CWT methods can be difficult and costly. Natural smolt tagging experiments in Puget Sound, Southern British Columbia, and the Washington Coast have generally supported the assumption that hatchery indicator and natural coho stocks are subjected to similar fishing patterns (see, for example, Weitkamp and Neely 2002). This relationship is less clear for chinook, but tagging experiments with progeny from natural and hatchery brood stock again suggest that the use of indicator stocks is reasonable.

Statistical uncertainty surrounding CWT-based estimates have also been the subject of increasing scrutiny. There are various sources of uncertainty surrounding CWT-based estimates and their application in salmon management processes. Statisticians recognize two components to uncertainty: variance and bias. Variance measures the (hypothetical) variation among estimated catches of and impacts on CWT groups of salmon based on recoveries of individual CWT fish as it may depend on magnitude of exploitation rates, size of CWT release groups, sampling rates in fisheries and spawning escapements, and can generally be calculated. Bias may be positive or negative and measures the difference between the expected (or average) value of estimates and the true but unknown quantities being estimated (e.g., total fishery-related mortalities). Magnitude of bias is extremely difficult to determine for several reasons. First, the true quantities being estimated are unknown. Second, the validity of assumptions made in calculations from which estimates are derived can be extremely difficult to rigorously test. For example, all cohort analyses for chinook salmon invoke an implicit assumption that marine natural mortality rates are invariant and have known values. Application of these fixed assumed values leads to unknown bias in resulting estimates. Another example would be application of assumed catch-and-release mortality rates for sub legal-sized (shaker) salmon that cannot be retained legally. Practical uncertainties in application of CWT-based estimates also result from the sparseness of historical data, the difficulty of conducting controlled experiments to test various assumptions, large errors in or nonexistent estimates of stray (non-hatchery) escapement of CWT fish, and demanding time frames for decision-making which place unrealistic demands on the capacity to report accurate data and perform required analyses.

These inherent statistical uncertainties were exacerbated by an unhappy convergence of factors. In the early 1990s, survival rates for many natural stocks declined precipitously and managers responded by reducing fishery impacts to try to maintain spawning escapement levels. As survivals plummeted and fishery impacts decreased, fewer CWTs were being recovered, thereby increasing statistical uncertainty with CWT-based estimates of fishery impacts and further reducing the reliability of inferences that could be drawn from such analyses. Also, managers have relied increasingly on alternative fishery management measures such as catch-and-release or species-selective fisheries. Taken together, the result has been that non-landed mortalities now account for a much greater proportion of total fishery mortalities. Calculation of non-landed mortalities is especially problematic in species-selective fisheries (e.g., chinook only may be retained, but coho must be released) or mark-selective fisheries (e.g., only adipose-clipped fish may be retained) because non-landed mortalities have traditionally been calculated as a direct function of landed catch and assumed release mortality rates.

Reduced sampling rates in various components of fisheries have also decreased the reliability of CWT tag recovery data and also introduced unknown bias. Especially serious issues that generate unknown bias include incomplete, inconsistent or nonexistent sampling programs for estimation of freshwater escapement (especially non-hatchery, stray escapement) and freshwater sport fishery catches of CWT fish. Finally, in some areas the numbers of unreported commercial catches are increasing but these catches may not be sampled at all, thus creating many *non-response* strata and generating negative bias in estimates of catches from CWT release groups. Analysts of CWT data have become progressively more aware and more concerned about these problems, but these issues did not reach crisis levels until the mid-late 1990s.

Increasing Complexity of Fisheries

Over the course of the last two decades, the PSC and fishery managers have sought to obtain information at finer and finer scales of fishery-time resolution to address conservation concerns for individual stocks. However, as strata become more refined, the uncertainty surrounding estimates of exploitation rates increases. This conflict between the needs of managers for information at increasingly finer levels of resolution and the increased uncertainty associated with the estimates made at these finer levels of resolution can be illustrated by examining the history of the PSC's chinook model.

In the early 1980s, during negotiations between the United States and Canada on a salmon treaty, a bilateral group of scientists was tasked with the responsibility of analyzing CWT data for chinook salmon in response to growing concerns over an emerging coast-wide conservation problem. The initial analyses were performed on the basis of total brood year exploitation rates so all fisheries and ages were combined into a single strata. The simple model constructed on the basis of this level of analysis proved sufficient to compare existing levels of fishery exploitation to levels believed to be sustainable by stocks managed for maximum sustained harvest. The model established a target reduction in brood year exploitation rates to rebuild depressed stocks to desired levels. As the negotiations proceeded, attention turned to determining how the conservation responsibility would be shared between the U.S. and Canada leading to a requirement to increase the level of fishery stratification in the model. Because terminal

fisheries had already been restricted to protect spawning escapements of individual stocks and because the conservation concern was coast-wide, the principal focus of the negotiations centered on the four principal mixed stock fisheries that accounted for the predominant impacts on the limited set of stocks for which CWT data were available (Southeast Alaska troll, North-Central B.C. troll, West Coast Vancouver Island Troll, and Strait of Georgia Troll and Sport). When agreement on the PST was ultimately reached in 1985, the model had grown to represent ten fisheries in annual time steps. During implementation of the 1985 treaty agreement, the Parties to the Pacific Salmon Treaty relied increasingly upon the model to help plan their fishing strategies. This led to demands for more refined resolution of fisheries. Currently, the CTC model represents 25 fisheries and a single annual time step. Because of limitations in available software and computing power, the model was "maxed" out by the combination of stocks, fisheries and time periods. But managers still desired finer levels of resolution. In the mid 1990s, the PSC's Chinook Technical Committee initiated an effort to recode the model to allow unlimited representation of stocks, fisheries, and time periods. Presently, plans are under development to represent over 100 fisheries, greatly increase the number of stocks represented beyond the current 30, and accommodate four time steps per year (Figure 2).

From an estimation perspective, in 1985 fisheries analysts were charged with estimating fishery-specific exploitation rates in just ten annual fisheries, whereas future demands may be for estimation of almost 400 fishery-time-specific exploitation rates. This increasingly fine scale of resolution that seems required (or desired) by fishery managers can only come at the expense of greatly increased estimation uncertainties within individual fisheries (see Appendix G).

Mass Marking and Mark-Selective Fishing

As survivals plummeted, the uncertain capacity of natural stocks to continue to persist brought the U.S. Endangered Species Act (ESA) into play. Several natural stocks of chinook and coho impacted by PSC fisheries were listed as threatened or endangered. These listings led to increased restrictions on fishery impacts, reduced access to hatchery fish, and CWT tag recovery data were now relied upon to establish management objectives such as jeopardy standards and to monitor fishery impacts on listed stocks for compliance with these standards.

The inability to fully harvest fish produced by hatcheries due to concerns for natural stocks, particularly in fisheries that exploit complex stock mixtures, led fishery managers and politicians to explore alternatives that might allow increased harvest of abundant hatchery fish while still achieving reduced impacts on natural populations. Rutter (2004) described the situation as follows:

> *"Why produce the fish if they cannot be harvested?" became both a legitimate question and a compelling argument for change in our fishery management regimes. Not surprisingly, several management agencies increasingly began to turn to mass marking and mark-selective fisheries, if not as an answer to the conservation problems of weak natural stocks, at least as a valuable tool for sustaining important fisheries in the face of wild fish constraints.*

Chinook model with 10 fisheries
For each stock, by age with annual time period.
Four stocks in model

Chinook Model with 25 fisheries
For each stock by age with annual time period
Thirty stocks in model.

Chinook model of future with over 70 fisheries, for each stock, by age and with four time periods. Model will have over 30 stocks

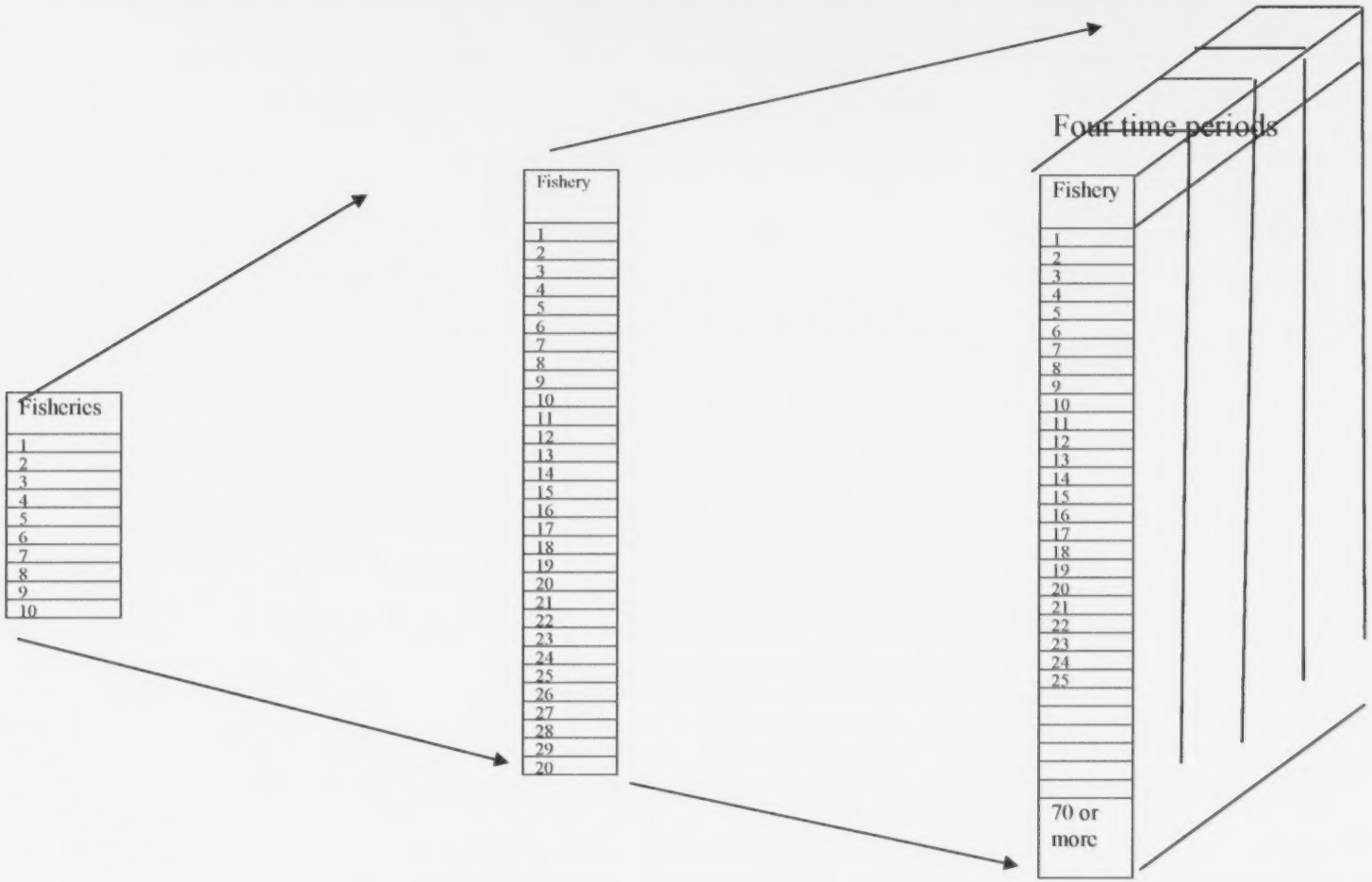


Figure 2. Fishery time step strata for each CTC exploitation rate indicator stock used in Chinook Technical committee model at different levels of resolution.

The alternative that has emerged is termed Mass Marking (MM) and involves marking hatchery fish to enable them to be visually identified.[6] Mark-selective fisheries (MSFs) are conducted under regulations that allow retention of marked fish but require that unmarked fish be released. Because mortalities of unmarked fish can no longer be directly observed as landings in MSF, they must instead be inferred through assumptions involving non-landed catch-and-release mortality rates. While some of the unmarked fish will die as a result of catch-and-release mortality in MSF, the expectation is that the magnitude of this catch-and-release mortality will be much less than the fishing mortality suffered by marked hatchery fish that may be retained.

Although it is no doubt true that the magnitude of catch-and-release mortality would typically be much less than the fishing mortality suffered by marked hatchery fish that may be retained, thereby allowing greater harvest of hatchery fish, intensive MSF could have a devastating impact on the long-term viability of CWT tag recovery programs. Because marked hatchery fish and unmarked natural fish are no longer subject to the same patterns of exploitation under MSFs, CWTs on hatchery indicator stocks can no longer serve as surrogates to evaluate and monitor presumed fishery impacts on natural stocks. Unless the catch-and-release mortality rate were 100%, the assumption that wild and hatchery fish share equal exploitation rates would be violated in MSFs.

Thus, although MM and MSFs had promise for increasing harvests of hatchery fish while keeping fishing impacts on natural populations within desired constraints, these same programs threatened to jeopardize the commitment made by the United States and Canada to maintain a viable CWT program. In response, the PSC established an ad-hoc Selective Fishery Evaluation Committee (ASFEC) to investigate issues surrounding MM and MSFs and to develop potential solutions to problems.

ASFEC (1995) issued its report in 1995, defining a viable CWT system as one that:

1. *Provides the ability to use CWT data for assessment and management of wild stocks;*

2. *Is maintained such that the uncertainty in stock assessments and their applications does not unacceptably increase management risk; and*

3. *Provides the ability to estimate stock-specific exploitation rates by fishery and age.*

The ASFEC also recommended that consideration of MM and MSF be limited to coho[7] and determined that the adipose fin clip provided the most promising mass mark for hatchery fish **if** MM and MSFs were to be pursued. The recommendation to employ the adipose fin as a mass mark resulted from several factors: (a) MM mortality and fin regeneration were believed to be

---

[6] MM can also improve the capacity to monitor the status of natural stocks by providing a convenient means of facilitating the identification of hatchery fish in spawning escapements. In many systems, especially for Chinook salmon, the contribution of stray hatchery fish to natural spawning grounds cannot be determined due to inadequate and variable hatchery marking programs. Hankin (1982) showed that "constant fractional marking" programs, where a constant fraction of hatchery releases (< 100%) receive an identifying mark, can allow estimation of the proportion of hatchery fish in freshwater returns. MM (100% marking) is the most extreme version of a constant fractional marking program.

[7] Chinook were not recommended for MM and MSF for a variety of reasons, including (a) the small size of fall-type fish at release; (b) the physical infeasibility of MM large numbers of Chinook within the limited time the fish are available in hatcheries; (c) the complex life history and exploitation pattern of this species; and (d) the extensive migrations of this species.

minimal compared to other fin marks such as a ventral fin clip; (b) the adipose mark could be inexpensively applied and marking methods and costs were known with reasonable certainty; (c) information could be readily provided to enable fishermen to recognize the missing adipose fin as a visual identifier for hatchery fish.

In 1977, the adipose fin was sequestered for exclusive use as an indicator of the presence of a CWT. As Table 1 below illustrates, however, the adipose clip is no longer consistently reserved for use with fish receiving CWTs.

Table 1. Required Use of the Adipose Fin Mark with the CWT (Final Minutes of the 2004 Mark Meeting of the Pacific States Marine Fisheries Commission, convened in Lewiston, ID. May 12-14, 2004).

Region	*Chinook*	*Coho*	*Steelhead*	*Sockeye*	*Chum*	*Pink*
Alaska	***Yes***	***Yes***	*No*	***Yes***[a]	***Yes***[a]	***Yes***[a]
Canada	***Yes***	*No*	*No*	*No*	*No*	*No*
Washington	*No*[b,c,d]	*No*	*No*	*No*	*No*	*No*
Oregon	*No*[b,c]	*No*	*No*	*No*	*No*	*No*
Idaho	*No*[c]	*No*	*No*	*No*	*No*	*No*
California	***Yes***	***Yes***	*No*	*No*	*No*	*No*

Where 'Yes', the only use of the Adipose clip is to indicate a CWT. *These requirements apply equally if the adipose is clipped in combination with another fin(s).*

a/ Adipose fin marked steelhead, sockeye, chum and pinks do not require a CWT because there is no coastwide recovery program for tags in these species. Alaska is an exception in requiring a CWT in adipose marked sockeye, chum and pinks.

b/ A CWT is presently required with the adipose fin clip for all chinook from the Strait of Juan de Fuca and coastal Washington and for fall chinook from the Columbia Basin.

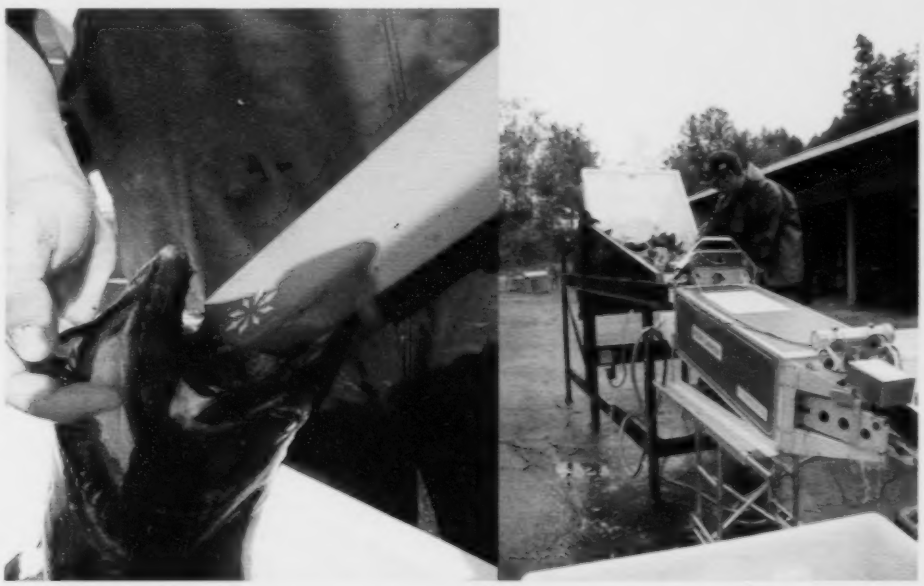
c/ Use of a CWT with the adipose clip is currently being resolved for spring chinook from the mainstem Columbia River above Bonneville Dam. Adipose mass marking of Snake River spring chinook has been approved by majority vote of the Pacific States Marine Fisheries Commission's Mark Committee

d/ Use of the CWT with an adipose clip on summer chinook in the Columbia River remains unresolved. Adipose only mass marking of Snake River summer chinook has been approved by majority vote of the Mark Committee.

The ASFEC recognized that if the ad-clip were instead used as a mass mark, then the number of fish with missing adipose fins would increase many times over. Some other means would need to be found for agencies to be able to continue programs to recover CWTs. The ASFEC recommended that this problem could be overcome by using electronic tag detection (ETD) as a means of detecting the presence of CWTs among adipose-clipped fish.

Two main types of ETD equipment have been used: a hand-held wand and a tube. Wands are designed for use by field samplers who inspect fish in catches and escapements. A wand is

passed over the head of fish (coho) or inside the mouths of large fish (chinook) and a beep identifies the detection of metal. Tube detectors are designed to be employed in high-volume installations such as hatcheries and processing plants where entire fish may be passed through the detector and the presence of a tag determined. ETD technology must be used by trained samplers and should be employed throughout the migratory range of the stocks to ensure recovery of CWTs required for cohort analysis. However, some jurisdictions that do not conduct MSFs continue to rely only upon visual sampling of catch and have not agreed to deploy ETD in some areas due to budgetary reasons (increased cost of equipment and sampling) or due to unresolved technical or operational concerns (e.g., concerns regarding accuracy of wand detection of CWTs among adipose-clipped MM fish). Unless heads are taken from all adipose-clipped fish that are sampled from catches and are later searched for CWTs, absence of ETD throughout the migratory ranges of affected stocks will generally mean that estimates of CWT recoveries in ocean fisheries and in spawning escapement will be negatively biased, resulting in biased estimates of exploitation rates of hatchery fish and creating increased difficulty in assessing performance of PSC agreements.



Wand and tube CWT detectors

Even if all jurisdictions were to use ETD technology to screen all adipose-clipped fish in samples, this innovation would not preserve the ability of CWT tag groups to serve as surrogates for natural stocks. To allow estimation of fishery impacts on natural stocks, ASFEC proposed that a system of *Double Index Tagging* (DIT) be used. With DIT, two groups of CWT'd fish are released, identical in every respect except that: (a) the groups carry different CWT codes; and (b) only one of the groups is adipose-clipped (Mass Marked). In MSFs, fish from the unmarked DIT pair are released whereas fish from the marked DIT pair are retained. In non-selective Fisheries (NSF), CWT recoveries would be collected from both tag groups in a DIT pair. Differences in recovery patterns between the two DIT groups would represent the effect of MSFs (Figure 3).

The DIT strategy was believed to be capable of generating data to preserve the viability of the CWT system.

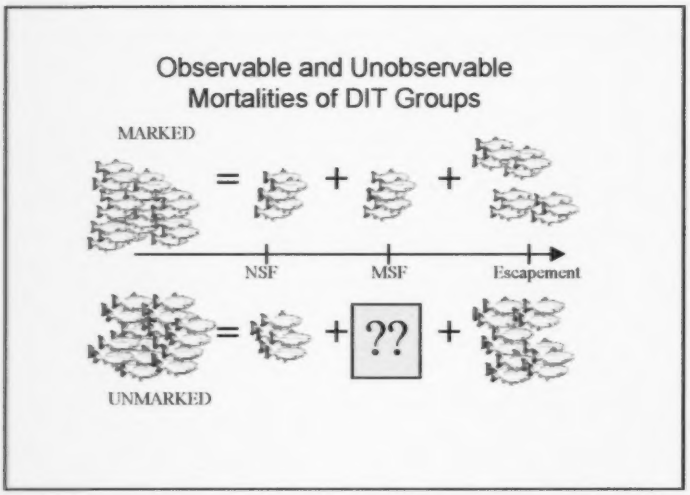


Figure 3. Conceptual Schematic of DIT Releases and Recoveries in non-selective fisheries (NSF), mark-selective fisheries (MSF) and freshwater escapement.

The DIT system effectively doubled tagging costs for indicator stocks because now two groups of fish would need to be tagged. Further, CWT recovery programs for DIT fish captured in nonselective fisheries and in spawning escapements now had to sample both marked and unmarked fish. These changes in sampling requirements - the need to sample both unmarked and marked fish (for DIT) and to use ETD (because the adipose clip is used for MM without CWT) - greatly increase the cost of maintaining the CWT system. Also, the DIT system and MSF has generated new data reporting requirements and increased opportunities for errors in release and recovery information reported to PSMFC and stored in the PSMFC database system (RMIS). These new reporting requirements include at least the need to indicate whether or not a code is a marked or unmarked member of a DIT group; whether the fishery in which a DIT group individual is recovered was mark-selective or not; and whether individuals were detected visually or electronically.

Even with ETD and DIT, however, the capacity to generate stock-, age-, and fishery-specific exploitation rates from CWT recoveries remains uncertain. The ASFEC and its successor, a permanent Selective Fishery Evaluation Committee (SFEC) established by the PSC in 1998, noted that no methods had yet been found to generate reliable estimates of MSF impacts on unmarked fish when more than one MSF impacted a stock. Zhou (2002) expressed skepticism about the reliability of inferences drawn from DIT data. Lawson & Comstock (1995) reported that MSFs could generate biased estimates of fishery impacts on unmarked stocks. Lawson & Sampson (1996) identified potential issues with the accurate estimation of mortalities of

unmarked DIT releases which could arise in the conduct of MSFs. Finally, numerous issues and questions regarding both the basic CWT program and the use of DIT to evaluate MSFs were identified in a 2003 report by the Joint Coho DIT Analysis Workgroup. The evaluation of the first three years of MSFs on coho salmon from Puget Sound and the Washington Coast found holes in the basic CWT program, including the failure to sample all fisheries and escapement for CWT. Application of the DIT groups to estimates MSF mortality was sometimes not possible because the assumptions of the program (i.e., equal treatment of marked and unmarked components of the DIT group) were not met. The impacts of selective fisheries could generally not be detected because of the small magnitude of the MSF, but a statistically significant difference did exist in the estimated exploitation rates in some years on marked and unmarked coastal stocks. The feasibility of using the DIT strategy for chinook salmon has been much less well studied and seems even more problematic."

Nonetheless, Canada and the United States currently mass mark millions of hatchery coho each year and the United States has also mass marked millions of chinook salmon in recent years. New technology has been developed to automate the process of mass marking and/or inserting CWTs into large numbers of hatchery-produced chinook and coho (Figure 4) and the pressure to mass mark hatchery fish has reached new levels. Indeed, Rep. Norm Dicks, D-Wash., recently inserted a new mass marking requirement into the Interior Appropriations bill which was passed as part of a multi-agency funding bill in 2003 (Bowhay 2004). Section 138 of this bill states:

> *"The United States Fish and Wildlife Service shall, in carrying out its responsibilities to protect threatened and endangered species of salmon, implement a system of mass marking of salmonid stocks, intended for harvest, that are released from Federally operated or Federally financed hatcheries including but not limited to fish releases of coho, chinook, and steelhead species. Marked fish must have a visible mark that can be readily identified by commercial and recreational fishers."*

This US mass marking directive has been included annually in appropriations bills since 2003. As a consequence of this legislation, mass marking will occur on many millions more chinook and coho salmon originating from Pacific Northwest hatcheries, almost certainly relying on the adipose fin clip as the mass mark. Many of these fish will migrate to areas where there are no plans to employ ETD or to propose MSF. As Rutter (2004) stated in his opening remarks for the CWT Workshop, *"The train of mass marking and mark-selective fisheries is moving rapidly down the tracks, and doesn't look like it will be stopped anytime soon."*

In the early 1990s, when MM and MSF were in their infancy, the PSC found itself at the center of heated policy and technical debates over the potential impacts of these new hatchery fish marking and harvest strategies on the integrity and viability of the CWT system. Recognizing the reality that political pressures would press for continued implementation of MM and MSF, the PSC ultimately adopted an "Understanding of the PSC Concerning Mass Marking and Selective Fisheries" and established a permanent Selective Fisheries Evaluation Committee (SFEC) in 1998. The SFEC investigated technical issues relating to MM and MSF for chinook (SFEC 2002) and developed templates and protocols for evaluating agency proposals for MM of hatchery fish and for MSF. (The terms of reference for the SFEC and details of proposal

templates, which were revised by the PSC in February 2004, are available through the PSC office in Vancouver, British Columbia.) Despite substantial efforts, however, the SFEC has not been able to resolve specific analytical problems caused by MM and MSF. Most notably, the SFEC has not been able to develop a method to reliably estimate fishery mortality on unmarked natural stocks that may be subjected to multiple MSFs. In the future, it seems likely that many salmon stocks will be subjected to a sequence of nonselective and mark-selective fisheries.

Figure 4. **AutoFish System from Northwest Marine Technology is capable of automated removal of the adipose fin and/or insertion of a CWT. Each fish is sorted by size, clipped and/or tagged, and returned to the pond in about 5 seconds.**

An additional and serious consequence of MM and MSF has been a gradual loss of the kind of cooperation, coordination and consistency of programs that characterized the first two decades of the CWT tag recovery program. As the Tables 2 and 3 below indicate, ETD remains inconsistently applied, and, in some jurisdictions, marine recreation sport fisheries are not sampled by trained fishery technicians, but estimated recoveries are instead based on voluntary returns by recreational fishermen.

The CWT Workshop

As more and more of the fishing mortality on natural stocks is accounted for by non-landed catch (i.e., mortalities due to shaker loss, drop off, catch-and-release), the existing CWT system is being increasingly challenged. Requirements to constrain exploitation rates on depressed natural stocks are increasing and reliable estimates of total mortalities are being demanded, but the

information systems necessary to provide these required estimates are deteriorating. Estimates of mortalities on natural stocks are becoming ever more dependent upon assumptions, inferences, and methods that cannot be readily validated. This is treacherous ground at a time when consequences of error may be serious for ESA-listed natural populations and when demands for future information will require increasing accuracy and greater stock-specificity.

Table 2. Fishery Sampling Methods for Coded Wire Tagged Coho

Region	Fishery	Type of Sampling	Comments
Alaska	Commercial	Visual	
	Sport	Visual	
Northern BC	Commercial	Visual	Some terminal areas are not sampled
	Sport	Voluntary (Visual)	Anglers encouraged to return heads only from marked coho; therefore tag recoveries of unmarked coho are not expected.
West Coast Vancouver Island	Commercial	Electronic	Incidental recoveries in fisheries on other species; non-retention of unmarked coho
	Sport	Voluntary (Visual)	Anglers encouraged to turn in heads only from marked coho; therefore tag recoveries of unmarked coho are not expected.
Strait of Georgia	Commercial	Electronic	Incidental recoveries in fisheries on other species; non-retention of unmarked coho
	Sport	Voluntary (Visual)	Anglers encouraged to turn in heads only from marked coho; therefore tag recoveries of unmarked coho are not expected.
Puget Sound	Commercial	Electronic	
	Sport	Electronic	
Washington Coast	Commercial	Electronic	
	Sport	Electronic	
Oregon Coast	Commercial	Electronic	
	Sport	Electronic	
Columbia River	Commercial	Electronic	
	Sport	Electronic	

Although it is relatively easy to identify 'problems and shortcomings' of the CWT system, it is much more difficult to imagine some other system that might replace the existing CWT system or provide new information that might somehow 'repair" the existing CWT system. Since the CWT was developed, new technologies have emerged. Movements of individual fish can now be tracked using radio transmitters or data storage tags that record magnetic position, heading, temperature, depth, salinity, pressure, light, chemical and physiological indicators at set intervals of time. The Pacific Ocean Shelf Tracking project, involving the deployment of acoustic receiver arrays along the Pacific coast to record serial numbers transmitted from specially

designed tags, has recently been initiated (for further information, see *http://www.postcoml.org/*). Remote data telemetry systems are under development to provide real-time information on individual animals. Although such systems are presently applied to birds, ungulates, cetaceans and billfish, further miniaturization may eventually make them suitable for salmon. Passive Integrated Transponder (PIT) tags can be read without killing the host as fish pass by sensors.

Table 3. Fishery Sampling Methods for Coded Wire Tagged Chinook

Region	Fishery	Type of Sampling	Comments
Alaska	Commercial	Visual	
	Sport	Visual	
Northern BC	Commercial	Electronic	Tags from unmarked fish, except those recovered from freezer boats, are not decoded
	Sport	Voluntary (Visual)	Anglers encouraged to turn in heads only from marked chinook; therefore tag recoveries of unmarked chinook are not expected.
West Coast Vancouver Island	Commercial	Electronic	Tags from unmarked fish, except those recovered fi freezer boats, are not decoded
	Sport	Voluntary (Visual)	Anglers encouraged to turn in heads only from marked chinook; therefore tag recoveries of unmarked chinook are not expected.
Strait of Georgia	Commercial	Electronic	Unmarked tags not decoded
	Sport	Voluntary (Visual)	Anglers encouraged to turn in heads only from marked chinook; therefore tag recoveries of unmarked chinook are not expected.
Puget Sound	Commercial	Electronic	
	Sport	Electronic	
Washington Coast	Commercial	Electronic	
	Sport	Electronic	
Oregon Coast	Commercial	Visual	
	Sport	Visual	
Columbia River	Commercial	Electronic	
	Sport	Electronic	

Biological marks, whether natural (e.g., genetic, parasites) or man-induced (e.g., otolith, chemical or genetic) provide other means of identifying the stocks to which individual fish belong. Can new technologies under development provide information that can strengthen the

CWT system or fill some of its glaring voids? Could new technologies provide the data required to estimate exploitation rates on natural stocks at acceptable cost and thus supplant the CWT as the principal information source for PST management of chinook and coho salmon?

In early June of 2004, the PSC sponsored a 4 day workshop on the future of the CWT program. A panel of experts in various fields of fisheries science (Panel, see Appendix I) was brought together to examine the current status of the CWT system in light of the fishery management challenges that lie ahead. In announcing the workshop, the PSC described the task of the Panel in broad generalities:

> *The workshop is intended to examine limitations of the CWT program and to evaluate the capacity of alternative technologies to provide data to improve assessment of chinook and coho salmon. While the charge for the workshop is from the Pacific Salmon Commission and concern for our ability to estimate age and stock specific mortality rates by fishery, these data have many other uses (e.g., monitoring compliance with jeopardy standards established pursuant to the U.S. Endangered Species Act and for hatchery specific experiments). Also, data collected using alternative technologies (such as genetic information, otolith marks, or other tags) may provide opportunities to augment a modified CWT-based system.*

More explicit expectations were expressed by Rutter (2004) in his introductory remarks to the workshop:

> *At the end of this process,... our hope is that the expert panel will produce a report, one that will have very real and significant impacts on the current CWT program that is implemented by agencies coast-wide. ... we undertook this initiative ...to help define the coast-wide fishery management and stock assessment infrastructure of the future, and the steps needed to put it in place.*
>
> *From my perspective, then, the success or failure of this workshop and subsequent follow-up efforts will be defined by two primary criteria: (1) the extent to which the report produced by the panel contains practical recommendations for effective solutions to the perceived shortcomings of the CWT program as it exists today; and (2) the extent to which the recommendations actually are implemented by the management agencies in a coast-wide, coordinated manner. My hope is that the deliberations of the expert panel ultimately will result in a set of consensus recommendations addressing the first criterion. To the extent those recommendations are scientifically sound and practical,; it will be up to us in the salmon management community to develop a coordinated plan to implement them.*
>
> .....
>
> *Whatever the advice turns out to be, the report will have to make a compelling case. The logic behind recommended changes and their benefits must be clear, particularly if they involve new fiscal resources. If we are to succeed in implementing the report... the recommendations must enjoy a high degree of acceptance by the agencies that are responsible for their implementation.*

The Panel was thus charged with a very specific and rather narrow analytic task:

> *To determine what methods, CWT or otherwise, might be used to estimate age- and fishery-specific mortality rates of salmon from natural stocks in the face of mass marking and mark-selective fisheries.*

But the Panel was asked to accomplish this task within the much broader context of the future infrastructure that may be needed for coast-wide fishery management and stock assessment by the PSC.

We found that our efforts to address the narrow and focused task that prompted the workshop (estimation of age- and fishery-specific mortality rates) inexorably led us to engage in a much broader review of a large number of fundamental issues that concern management of salmon fisheries by the PSC. The findings and recommendations that we present in this report are therefore not limited to the narrow analytic task with which we were faced, but also address other fundamental assumptions or concerns that we identified through our review and which, in general, concern the basic infrastructure that may be needed to support future salmon management by the PSC.

PART II. EXECUTIVE SUMMARY

Our major findings and recommendations are grouped thematically and accompanied by brief background information that provides context.

MAJOR FINDINGS

The Coded Wire Tag Recovery System

The coded-wire-tag (CWT) system has provided a practical and efficient means for stock and fishery specific assessment for Pacific salmon because it: (a) includes fully integrated tagging, sampling, and recovery operations along the entire west coast of North America; (b) has sufficient resolution for specific assessments of uniquely identifiable experiments; (c) provides data conducive to standardized methods of analysis of stock and fishery assessments; and (d) facilitates multi-decade evaluation of trends in stock and fishery statistics such as survival indices and brood exploitation rates.

As an integral part of the 1985 Pacific Salmon Treaty (PST), the United States and Canada entered into an August 13, 1985 Memorandum of Understanding in which "the Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations." (Paragraph B). The Parties recognized the central importance of the CWT program to provide the data required to evaluate the effectiveness of bilateral conservation and fishing agreements.

The chinook and coho annexes of the PST are directed at constraining exploitation rates on naturally-spawning stocks in order to provide a means for sharing harvest and conservation responsibilities. The Chinook Technical Committee (CTC) and Coho Technical Committee (CoTC) are charged with assessing the implementation of these annexes and rely on CWT recoveries to complete the required analyses. These analyses: (a) require the capacity to estimate age- and fishery-specific exploitation rates for individual stocks; (b) depend upon the coast-wide CWT system to provide the data required to estimate exploitation rates; and (c) rely on the premise that exploitation rates and patterns on naturally spawning stocks can be accurately estimated from data collected from CWT experiments on hatchery fish surrogates.

Importance of the CWT Tag Recovery System

Finding 1. *The CWT system is the only technology that is currently capable of providing the data required by the PSC's Chinook and Coho Technical committees. There is no obvious viable short-term alternative to the CWT system that could provide the data required for cohort analysis and implementation of PST management regimes for chinook and coho salmon. Therefore, agencies must continue to rely upon CWTs for several years (at least 5+ years), even if agencies make decisions for development and future implementation of alternative technologies.*

Problems with the Existing CWT Tag Recovery System

Finding 2. *Historic shortcomings of the CWT recovery data system remain problems today. These problems include inaccurate or non-existent estimates of freshwater escapement, especially of stray (non-hatchery) escapement, and inadequate sampling of some fisheries (e.g., inadequate sampling of freshwater sport fisheries and direct sales).*

Finding 3. *Since the inception of the PST, the quality and quantity of CWT recovery data have deteriorated while increased demands have been placed on these data to provide guidance for protection of natural stocks at risk. Deterioration is due to a number of interrelated factors:*

a. reduced fishery exploitation rates, sometimes coincident with periods of poor marine survival, have resulted in fewer fishery recoveries of CWTs;

b. fishing regulations such as minimum size limits and non-retention fisheries have resulted in significant non-landed (catch-and-release) mortality that is infrequently, or cannot be, directly sampled;

c. changes in the economics of commercial fisheries in at least Washington have resulted in an increased percentage of the catch sold in dispersed locations that are difficult to sample;

d. increased escapement rates, a reflection of reduced ocean fishery exploitation rates, have increased the proportions of total adult cohorts that return to poorly sampled or unsampled natural spawning areas;

e. an increased proportion of the total catch is occurring in sport fisheries which are more difficult to sample than commercial fisheries;

f. competing demands for agency budgets have reduced support for CWT tagging efforts and CWT recovery programs in some jurisdictions.

Finding 4. *Fishery managers are becoming more concerned with obtaining information that cannot be readily obtained through direct observation or data provided by the CWT system. CWTs are not likely to be an effective tool to answer management questions that require identification of the origin of all fish encountered (e.g., stock-age composition of encounters of sub-legal sized fish) or the survival and migration routes of individual fish (e.g., migration patterns of released fish, catch-and-release mortality rates)*

Finding 5. *Although there appears to be substantial empirical support for the critical assumption that exploitation rates and patterns of hatchery indicator stocks are the same as those of associated natural stocks, there are few peer-reviewed, published studies on this topic, especially for chinook salmon. Much pertinent agency-collected data remains unanalyzed.*

Issues Raised by Mass Marking & Mark-Selective Fisheries

Prior to the initiation of extensive mass marking (MM) and marine mark-selective fisheries (MSFs) in 1993, the PSC established an ad-hoc Selective Fishery Evaluation Committee (ASFEC) to complete an assessment of the implications of MM and MSFs on the CWT system. ASFEC concluded that selective fisheries would disrupt CTC and CoTC analyses in two ways (ASFEC, 1995):

- MSFs "violate the fundamental assumption that the tagged to untagged ratio remains constant through the entire migration of a stock containing both marked and unmarked components. Estimates of fishery exploitation rates from samples of tagged and marked fish will still be unbiased estimates of untagged and marked fish, but *not* of fishery exploitation rates of unmarked fish." As MSFs increase in number and intensity, the discrepancy between the fates of adipose-clipped fish and unmarked fish will increase.

- MSFs result in non-landed mortalities to unmarked fish and "there will no longer be landed catch of unmarked fish to sample as a basis for estimating fishery impacts."

If MSFs were implemented for coho salmon, the ASFEC (1995) recommended: a) an adipose clip as the mass mark; b) ETD for CWTs; and c) double-index tagging of marked (Ad+CWT) and unmarked (CWT only) hatchery groups. The ASFEC (1995) noted that "even with these efforts, however, some information and aspects of the present CWT program will be compromised or lost. The degree to which information is lost is directly related to the size of the selective fishery program" and "we will not be able to estimate fishery-specific mortalities on unmarked stocks when multiple selective fisheries occur."

The ASFEC recommended that MM and MSFs for chinook not be pursued when it issued its 1995 report because: (a) the technology to MM large numbers of small fish was not available and there were concerns of excessive mortality associated with the necessity to handle the fish

shortly before release; (b) the complex life history of chinook increased the difficulty of assessing impacts of mark-selective fisheries for this species; and (c) impacts would likely extend coast-wide, increasing the cost and difficulty of coordinating implementation.

Finding 6. *The Panel concurs with previous ASFEC findings that MM and MSFs together pose serious threats to the integrity of the CWT recovery data system. In particular, under MSF, recovery patterns for adipose-clipped fish are no longer suitable indicators of recovery patterns for unmarked natural stocks, and under MM there are significant practical and statistical issues raised by the need to find adipose-clipped and coded wire tagged fish (Ad+CWT) from among the much larger number of fish released with adipose clips only. As MSF increase in number and intensity, the discrepancy between the fates of adipose-clipped fish and untagged fish will increase. The seriousness of these threats was previously pointed out to the PSC in the 1991 memorandum reproduced as a frontispiece for this report and in the 1995 report of the ASFEC.*

Finding 7. *For both coho and chinook salmon, it appears possible to generate approximately unbiased estimates of* total *non-landed mortalities at age in all MSFs from a full age-structured cohort analysis of paired DIT releases of CWT groups. The accuracy of these estimated total non-landed mortalities may be poor unless very large numbers of fish are released in DIT groups. Estimates of total non-landed mortalities in all MSFs combined would not, however, meet requirements of current PSC regimes to estimate age- and fishery- specific exploitation rates.*

a. *There does not appear to be any unbiased method to allocate estimated total non-landed mortalities over a set of individual mark-selective fisheries. That is, overall non-landed mortality impacts may be unbiasedly estimated, but impacts in individual MSFs may not be.*

Finding 8. *We have serious methodological and sampling concerns regarding application of the DIT concept:*

a. *We have been unable to find convincing theoretical or empirical evidence that DIT approaches can generate precise, unbiased estimates of age-fishery-specific exploitation rates for natural stocks of chinook or coho salmon (represented by unmarked DIT release groups) in the presence of sub-stocks and multiple mark-selective ocean fisheries. Methods for analysis of DIT recovery data remain incompletely developed for: (a) complex mixtures of non-selective and mark-selective fisheries with varying exploitation rates and different catch-and-release mortality rates, and (b) the full age-structured setting required for chinook salmon.*
b. *The potential utility of DIT is undermined by the reluctance of some agencies to recover CWTs for both marked and unmarked DIT groups. This reluctance can be attributed in part to the additional sampling burdens and costs associated with the use of the adipose fin clip both as a mass mark and as a visual indicator for the presence of a CWT.*

Finding 9. *Concerns have been raised regarding "reliability in practice" of electronic wanding of salmon (especially large chinook) for presence of CWTs, but empirical evidence brought to our attention has consistently suggested that electronic wanding detection of CWTs is very reliable. Problems reported with electronic wanding appear to be operational in nature, centering on purchase and maintenance costs of equipment, availability of back-up detection equipment, training and supervision, increased sampling costs, etc.*

Finding 10. *Based on recent proposals, many chinook and coho salmon stocks affected by PST regimes may be impacted by increasingly complex mixtures of non-selective and MSFs. The overall impact of MSFs will be stock-specific, depending on migration and exploitation patterns. The potential complexity of these fisheries and the limitations of existing assessment tools have significant ramifications for fishery management:*

a. Management agencies have not yet developed a framework to address the increased uncertainty that would result from the initiation of significant MSFs.

b. Improved coordination of sampling and analysis will be required to maintain stock assessment capabilities.

Existing and Future Technologies that Might Complement or Replace the CWT System

Expert Panel members were provided with published reports, oral presentations, and email correspondence concerning currently available technologies and proposed future technologies that might somehow complement or replace the existing CWT system. Below we present our findings concerning two existing technologies and two emerging technologies that may have promise. The two existing technologies are otolith thermal marking and microsatellite-based genetic stock identification (GSI) methods. The emerging technologies are genetic - use of SNPs (single nucleotide polymorphisms) for stock or release group identification - and electronic - use of radio frequency identification (RFID) tags (electronic technology). We emphasize that even if these new technologies were introduced and supplemented or replaced the CWT system, **the serious problems that we have identified for estimation of non-landed fishing mortalities, made more serious by mark-selective fisheries, would not be eliminated. These problems would remain.**

Finding 11. *Some existing technologies can complement the existing CWT system. These technologies include at least otolith thermal marking and Genetic Stock Identification (GSI) methods.*

Finding 12. *These alternative existing technologies cannot, by themselves, replace the CWT system, but they might be used jointly to achieve a similar purpose (e.g., GSI + otolith thermal marking). Although such combination of technologies may be theoretically possible, their combined use could have substantial increased costs and would require a degree of interagency coordination and collaboration that exceeds that which was necessary to develop the CWT system.*

Finding 13. *Modern GSI methods can be used to estimate the stock composition of the landed catch in a particular time/area fishery. However, the accuracy and precision of data required to estimate stock-age-fishery specific exploitation rates using GSI methods is dependent upon a variety of factors. For example, microsatellite DNA-based GSI technology is not yet capable of generating consistent, replicable estimates due to the lack of a coast-wide genetic baseline, the history of stock transfers within and among watersheds, and differences in methodologies and mixture separation algorithms.*

Finding 14. *Although GSI methods can provide estimates of stock composition in catches or spawning escapements, they cannot provide (with the exception of full parental genotyping, FPG, see Finding 18) information on age or brood year contribution from a particular stock. This information is, of course, required for estimation of age-fishery-specific exploitation rates. Theoretically, GSI data could be augmented by aging data, e.g. scale ages, to rectify this difficulty. Unfortunately, we do not believe that reliable ages of chinook salmon or coho salmon captured in mixed stock ocean fisheries can be obtained consistently by reading of scales. Based on a review of published and unpublished studies, it seems clear that aging errors can be substantial and that these errors are largely attributable to ambiguities in identification of freshwater annuli (juvenile life history).*

Finding 15. *Large sample sizes will be necessary to use GSI methods to generate reliable estimates of fishery contributions for small (often natural) stocks, and results will be sensitive to small assignment errors for large stocks and ages.*

Finding 16. *If sampling programs were sufficiently well designed, GSI methods could be employed to gather information on the incidence of particular stocks and identify opportunities for time-area management measures to reduce fishery mortalities of natural stocks of concern. However, stock-specific management approaches in the aggregate abundance based management fisheries (AABM) would need to be carefully evaluated and agreed upon by the PSC to ensure that the harvest rates on other stocks do not exceed the target levels appropriate for the AABM abundance index as established under the 1999 PST agreement.*

Finding 17. *Over the past 20 years, first allozymes and more recently microsatellite markers have become the dominant tool for use in GSI. However, we believe that microsatellites will be replaced in the next several years by SNPs as the tool of choice for population genetic applications, as has already occurred in human genetics. The first step in the transition in marker type is the identification of appropriate SNP markers, a process that is already underway for chinook salmon through a multi-agency effort. SNP marker development and databases are also well underway for sockeye and chum salmon. Factors driving the replacement currently include the ease of data standardization, cost, and high throughput. Cost-effectiveness should rapidly improve as more SNPs are developed and multiplex processes drive the cost of analysis down.*

Finding 18. *A novel genetic method, termed full parental genotyping (FPG), has been presented as an alternative to coded wire tagging. The method uses genetic typing of hatchery brood stock to "tag" all hatchery production. The tags are recovered through parentage analysis of samples collected in fisheries and in escapement. Because of the need for a low laboratory error rate, FPG would rely on SNP markers. FPG would provide the equivalent of CWT recovery data, and could be easily integrated with a GSI system to provide stock of origin for all fish and stock + cohort for fish from FPG hatcheries. However, further evaluation of the relative costs of FPG, GSI and CWT systems is needed. Moreover, an empirical demonstration is needed to validate theoretical results that suggest broad feasibility*

Finding 19. *A number of existing or emerging electronic technologies could theoretically replace the CWT and may have substantial advantages over the CWT (e.g., tags can be read without killing the fish, unique tags for individual fish allow migration rates and patterns to be directly observed). Examples include at least Passive Induced Transponder (PIT) tags and Radio Frequency Identification (RFID) tags. PIT tags are currently too large to mark all sizes of juvenile chinook salmon released from hatcheries and are expensive relative to CWTs, but future technological improvements may reduce tag size and tag cost for these technologies.*

MAJOR RECOMMENDATIONS

Correct Current Deficiencies in CWT System:

Remedial measures should be undertaken immediately to correct deficiencies in data collection and reporting throughout the basic CWT system and to improve analysis of CWT recovery data.

Our findings indicate that the CWT system should remain the primary stock assessment tool for the CTC and CoTC in the short-term (5-10 years). Substantial staff and funding investments will be required to improve the reliability of this system, especially if MSFs are increased in number and intensity. Even if decisions are made now to develop and implement alternative technologies for future PST fishery management, it will be important to maintain a reliable CWT system during the transition period to ensure data continuity and to allow evaluation of the relative performance of some new technology or approach as compared to the CWT system.

Recommendation 1. *Substantial improvements must be made in the CWT system to insure that the quality and reliability of collected data are consistent with the increasing demands being placed on these data by fishery managers. Areas requiring attention include quality control/quality assurance, and various sampling design issues including expansion of catch and escapement samples in areas where little or no sampling currently takes place.*

Recommendation 2. *Explicit criteria should be developed for the precision of statistics to be estimated from CWT recovery data. New guidelines for CWT release group sizes and for fishery and escapement sampling rates should be based on these explicit criteria.*

Recommendation 3. *The utility of a decision-theoretic approach, integrating costs, benefits, and risk into a formal evaluation structure should be investigated as a means of prioritizing potential improvements (e.g., measures to improve CWT data reporting, sampling designs, and protocols) to the CWT system. The approach should identify the release group sizes and recovery programs required to meet the statistical criteria for CWT recovery data. Sampling programs should include all fisheries, hatcheries, and spawning ground areas where CWT exploitation rate indicator stocks are present.*

Improving tagging and sampling programs is important, but completion of the following recommendations will strengthen the analysis and interpretation of CWT data:

Recommendation 4. *We recommend completion of a comprehensive survey and statistical analysis of all relevant published and unpublished CWT studies that concern the correspondence between exploitation patterns and rates for hatchery indicator stocks as compared to their natural counterparts. This review should also include new analysis of relevant agency-collected data that have not yet been previously subjected to analysis. Recommendations for additional studies should be made if they are judged necessary.*

Recommendation 5. *Evaluate the utility of band-recovery or state space modeling approaches to estimate exploitation rates and maturation probabilities from cohort reconstructions based on CWT recovery data. These alternative modeling schemes may allow information from multiple cohorts to be combined to improve estimators compared to current single-cohort methods for which each cohort is treated independently.*

Respond to Mass Marking and Mark-Selective Fisheries

Implement enhancements to the basic CWT system and introduce new analytical methods that are consistent with the anticipated scope of MSFs.

Implementation of MSFs will ultimately depend on value judgments that must somehow balance many competing factors: a) the benefits of wild stock conservation as compared to enhanced fishing opportunities; b) the financial costs of selective fishery implementation as compared to the fishery benefits; c) the degree of uncertainty in natural stock assessments that proves politically acceptable for fishery management; and d) the theoretical viability and costs of alternative management strategies that might meet policy objectives. If MSFs are extensively implemented, our Panel has identified analytical methods and short-term enhancements to the current CWT system that could provide improved stock assessment capabilities for the CTC and CoTC. The enhancements considered should depend on the scope of MSF, including the species targeted, the geographic location of the fisheries, and the intensity of fishery exploitation.

Recommendation 6. *To provide greater assurance that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSFs.*

Recommendation 7. *The Panel has conducted a preliminary evaluation of a number of potential enhancements to the basic CWT system and analytical methods that address the complexities introduced by MM and MSF's. This evaluation indicates that no single solution will provide precise and accurate estimates of the stock-specific mortality of unmarked fish over all types of MSF's. Instead, we recommend an approach in which marking, tagging, and analytical methods are linked to the anticipated intensity of mark-selective fisheries.*

We suggest that the SFEC, or other group appointed by the PSC, develop recommendations for both threshold levels and specific methodologies to refine this concept (Table 4).

Table 4. Estimation methods for unmarked mortalities in MSFs at varying MSF magnitudes.

Selective Fishery Magnitude	Tagging and Marking	Estimation Method for Unmarked Mortalities in Selective Fishery
Low	CWT-based indicator stock program with single tag code per indicator stock.	Method 1. Multiply CWT recoveries of adipose-clipped fish by selective fishery release mortality rate.
Moderate	Option A. CWT-based indicator stock program with double-index tagging (DIT).	Method 2. Multiply recoveries of marked fish by mark-selective fishery release mortality rate and the ratio of the unmarked to marked component of the DIT at release.
	Option B. CWT-based indicator stock program with double-index tagging (DIT).	Method 3. Total MSF mortality derived from differences in age-specific escapement rates (or terminal run) of marked and unmarked fish. Mortality allocated to individual fisheries based on distribution of recoveries of marked fish.
High	Option A. CWT-based indicator stock program with double-index tagging (DIT) and otolith marking.	Method 3. Total MSF mortality derived from differences in age-specific escapement rates (or terminal run) of marked and unmarked fish. Mortality allocated to individual fisheries based on sampling of otolith marked fish in paired fishery.
	Option B. CWT-based indicator stock program with double-index tagging (DIT) and otolith marking.	Method 4. Multiply encounters of marked fish in mark-selective fishery by ratio of adipose clipped and unclipped fish with otolith marks in a paired non-selective fishery.

Recommendation 8. *The PSC should explore the interest of fishery agencies in participating in a Grand Experiment to improve the basis for harvest management decisions coast-wide through an intensive program conducted over a short period of time. If interest is sufficient, the PSC should: (a) charge its Technical Committees (Chinook, Coho, and Selective Fishery Evaluation) with the task of preparing draft specifications for the Grand Experiment; (b) solicit proposals to assess the feasibility of conducting the experiment and develop a detailed experimental design, including cost estimates; (c) seek funding for implementation; and (d) coordinate conduct of the experiment.*

Develop a Coordinated Research & Implementation Plan

Recommendation 9. *The PSC and management agencies should initiate a coordinated research and implementation plan to assure application of improved technology in the management of salmon fisheries.*

Recommendation 10. *Additional experiments should be conducted to evaluate the use of alternative external marks (e.g., a ventral fin clip or some alternative fin clip) for identification of fish bearing CWTs. Existing published information suggests that application of other external marks (e.g., a ventral fin clip) will reduce the survival of hatchery fish from release to age 2, but there is little evidence of differences in survival or behavior of externally marked versus unmarked fish past age 2. We propose some experiments that would allow, among other things, testing of a null hypothesis that survival rates for (A) Ad+CWT+alternative external mark fish and (B) Ad+CWT fish are the same from age 2 on, i.e., that there is no lingering differential mortality due to, for example, ventral fin marking.*

Recommendation 11. *We recommend that programs be developed and implemented to enhance the capacity to apply genetic methods to stock identification problems of concern to the Pacific Salmon Commission.*

Recommendation 12. *We recommend that the Pacific Salmon Commission support an immediate evaluation of a coordinated transition for all salmon species from genetic stock identification (GSI) based on the use of microsatellite markers to GSI based on single nucleotide polymorphism (SNPs) markers. It is important to develop standard sets of species-specific SNPs and related protocols now, so that coast-wide implementation of SNP-based GSI will be cost-effective and efficient. The best approach to such a transition is for a multi-jurisdictional agency, such as the PSC, to coordinate broad, multi-agency collaborations such as those adopted during the development of the coast-wide allozyme data bases during the last decade or during the development of the CTC standardized Chinook microsatellite data base developed over the last two years. Such collaborative efforts should include provisions for future tissue sample availability from all stocks included, so as to provide for periodic improvement and expansion of the databases.*

Recommendation 13. *We recommend support of a "proof-of-concept" empirical validation of the Full Parental Genotyping (FPG) method for use in management of Pacific salmon fisheries. This validation should occur in chinook salmon and should include support for further SNP development, a series of paired CWT and FPG tag recovery experiments, as well as thorough evaluation of relative costs of implementing these methods and the sampling necessary to provide equivalent tag recovery data.*

Recommendation 14. *We recommend that a feasibility study be conducted to determine how PIT, RFID or other electronic tags might be used to generate data suitable for full cohort reconstruction.*

Consider New Management Paradigms

Recommendation 15. *PSC technical committees should explore potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation (or non-landed mortality) rates, but that would still ensure adequate protection for unmarked natural stocks of concern.*

Alternative types of fishing regimes might provide similar or improved conservation and economic benefits at lower cost to the management agencies. It is likely that technology that could substantially improve salmon management will become financially and operationally available within a 5-15 year horizon.

IMPLEMENTATION STEPS

The 15 recommendations presented in this report follow a natural sequence for implementation:

1. Correct current deficiencies in CWT system (recommendations 1-5);
2. Respond to Mass-marking and Mark-selective fisheries (recommendations 6-8);
3. Develop a coordinated research and implementation plan (recommendations 9-14);
4. Consider new management paradigms (recommendation 15).

The coded wire tag (CWT) program has been a uniquely successful long-term example of cooperation in resource management, and the data derived have proved to be indispensable in the development of management and assessment methods for chinook, coho, and steelhead. While numerous problems with the current coast-wide CWT program were identified during the review, the majority of concerns can be addressed by a renewed commitment to the marking and sampling programs designed to achieve an agreed set of objectives. However, new demands (e.g., need for age-fishery-specific exploitation rates in an increasing number of fishery recovery strata) placed on the CWT program will increase uncertainty in CWT-based estimates. It will be impossible to respond to these new demands unless marking and sampling programs are redesigned. Even with redesign of marking and sampling programs, there are serious questions regarding whether stock-age-fishery-specific exploitation rates for unmarked fish can be accurately estimated when multiple mark-selective fisheries impact a given release.

For at least the next 5 years, the Panel has concluded that CWTs are likely to remain the only agreed upon coast-wide tool capable of providing the data required to perform cohort analyses for individual release groups of chinook and coho salmon. Consequently, our first several recommendations address restoring the CWT program coast-wide to meet an agreed minimum set of objectives established by the PSC (and consistent with the Memorandum of Understanding within the PST).

The Panel recognizes the current legal requirement in the United States to mass-mark all chinook and coho salmon, and steelhead reared in federal hatcheries. Therefore, we have presented recommendations to respond to estimation problems that are raised by the development of mark-selective fisheries that are intended to take greater advantage of mass-marked hatchery salmon.

Although the Panel is in full agreement that all parties must make a renewed commitment to the CWT program, the Panel also acknowledges the capacity of alternative marking and/or identification systems to augment information from the CWT system and, in the future, to possibly replace the coded-wire tag. While the potential for these new technologies seems substantial, there is currently no agreed upon coast-wide system that could replace the CWT system and there is not agreement on which technology may offer the greatest opportunity for development. It seems clear that certain DNA-based stock identification methods could augment the CWT system and should be seriously considered when considering how to "restore" the CWT system.

Finally, the Panel recommends that management strategies should be adjusted to compensate for increased uncertainty in the capacity to accurately estimate stock-age-fishery specific exploitation rates. This recommendation is intended to ensure that management systems are consistent with the quality and quantity of data available and to ensure adequate protection of the unmarked natural stocks. We are unanimous in our concern that the proposed future versions of PSC management models, which may incorporate as many as 75 fisheries with 4 time steps each, would place unrealistic and impossible demands on data, whether from CWT recoveries or from some future technology.

These conclusions lead to a series of next steps, many of which should be acted on soon since progressive changes to the CWT program require information to be derived from these steps. However, the Panel recognizes that the priority of specific steps will depend on future decisions and may differ from the sequence presented below:

1) The PSC should request that the domestic agencies of both Parties implement corrective measures to assure that standards for sampling and estimation of catch and escapement are met, that CWT release and recovery data are accurately and timely reported to regional exchange points, that proposals for MM and MSF are presented to the PSC early in the annual fishery planning process, and that coordination and cooperation between coast-wide agencies be restored. Restoration of cooperation and coordination is imperative to fully utilize the CWT program (under any scenario for future change) and was a strength of the past program. Two previous reports of the PSC's SFEC have emphasized the necessity for coast-wide cooperation and this Panel strongly supports their conclusion. Data standards for these programs must be integrated with data requirements developed during Step 2.

2) In 2006, the PSC should establish a joint Canada-US technical committee to determine an agreed statistical basis for a restored coast-wide CWT program, including means to estimate uncertainty about age-specific exploitation rates for chinook and coho salmon, objectives for the program design (specifically for the PSC indicator stocks), and the decision-theoretic methods to optimize the information return given limited financial resources. To facilitate immediate implementation of this step, the Panel suggests the use of internal agency experts plus a contract for external experts in statistical design and modeling to implement the necessary analytical framework. The PSC should seek joint funding for this initiative.

3) The PSC should revisit the "desequestering" of the adipose fin and its current frequent use as both a mass mark and a visual indicator of fish containing a CWT. This confounding of indicators greatly increases the costs of recovering CWTs, and the unwillingness of some agencies to use ETD equipment has already lead to incomplete recoveries of unmarked fish which contain CWTs in non-selective fisheries. It is highly desirable to have different visual cues to identify mass marked and CWT fish. If fin marks are to be employed for these purposes, then a decision on which fin to use in MM is essential to financial planning and logistics of a revised CWT program, but a fully informed basis for this decision requires more information on the relative survival of salmonids marked with different fin-clips. The PSC should request agencies in Canada

and the United States to immediately design and conduct (commencing with the 2006 brood year) a coordinated study of the relative survival of fish marked with adipose fin clips as compared to other fin clips, e.g., pelvic fin clip. If fish in such studies were also mass marked using otolith thermal marking techniques, these studies might also allow assessment of the survival impacts of adipose fin clips. These studies should probably be focused on chinook salmon due to the likely greater impacts of marking on this species due to its smaller average size at release.

4) The quality of the CWT program has broad effects on the assessment and management of salmonid resources coast-wide. The data gained is critical to the development of management planning models and agreements developed within the PSC. Therefore, before any sweeping changes to the CWT program are implemented, the Panel recommends a "Grand experiment" (*Recommendation 8*) to provide current and high quality information (at a level of resolution to be decided in (1) above) for the continued evolution of management models and assessments. Such an experiment will require a number of years of data and will require a staged implementation of changes to the CWT program so the goals of this experiment are not compromised in mid-stream. The PSC is the local focus for designing this experiment and should seek to implement this study through the appropriate agencies within one year (fall, 2006).[8]

5) The Panel acknowledges that MM and MSFs are likely to continue to develop in the near-term and that some loss of information from the CWT program will occur. The significance of the bias and uncertainty resulting from MSFs will vary depending on their complexity and intensity. Consequently, the PSC's SFEC should be charged with a detailed evaluation of the merits of the proposed tiered assessment framework modeled on the conceptual framework presented in the discussion of Recommendation 7. In addition, the PSC should undertake efforts to investigate methods to compensate for increased uncertainty in management capabilities without increasing the risk to spawning objectives (mature returns) for the naturally produced populations. PSC working groups for chinook and coho salmon should establish agreements on: methods to quantify the increased uncertainty relative to a base-year; the risk tolerance to be applied; and who (i.e., what fisheries) should accept the cost of increased uncertainty due to executing a mark-selective fishery. This step should be completed and incorporated into the next negotiations of the chinook and coho annexes of the PST. This task will involve technical experts and policy makers and is best addressed within the PSC.

6) The PSC should immediately develop a coordinated research and implementation plan for the application of new technologies for use in salmon assessment and management. The Panel's recommendations identify three research issues that need to be addressed before any broader application of these tools is likely to be agreed upon coast-wide (see *Recommendations 12, 13 and 14*). Suggestions for proceeding with *Recommendations 12 and 13* are included in this Panel report, and merit support through the PSC Endowment funds. Further, *Recommendation 14* addresses the development and application of electronic tags (PIT, RFID or others developed). These tags are not currently applied for

[8] Steps 2 and 3 are of sufficient importance that funding should be considered through the PSC Endowment process for a fixed number of brood years.

management within the PSC but may have significant future value. To examine this potential, the PSC should solicit research proposals through a public request for proposals and fund research in the innovative application of such technologies.

7) In spring 2006, or at the earliest possible time, the PSC should host a workshop concerning potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation (or non-landed mortality) rates, but that would still ensure adequate protection for unmarked natural stocks of concern. The Panel believes that estimating age- and fishery-specific exploitation rates will become increasingly difficult in the future if the number and intensity of MSFs increase and if management models demand increased time/area resolution. The impact of these problems for estimation of stock-age-fishery-specific exploitation rates would depend on the total exploitation rates being imposed on a stock of interest and whether the CWT indicator stock continues to be representative of the naturally-produced salmon for which it is an indicator. Given the current and future difficulties in estimation of age- and fishery-specific exploitation rates on individual natural stocks, the Panel feels it is very important to explore alternative management regimes that would rely less on these estimated quantities. Since the chinook annex must be renegotiated in 2008, dialogue on alternative regimes should be initiated soon.

CITATIONS

ASFEC. 1995. Selective Fishery Evaluation. Ad-Hoc Selective Fishery Evaluation Committee report to the Pacific Salmon Commission. June 9, 1995. Available from the Pacific Salmon Commission, Vancouver, British Columbia, Canada. 193p plus appendices.

Bowhay, C. 2004. Implications of legislative directives to mass mark hatchery production. Paper presented at PSC Workshop on future of the coded wire tag system, June 7-10, 2004.

Cooney, T. 2004. Current uses of Coded Wire Tag (CWT) program for chinook and coho salmon. Paper presented at PSC Workshop on future of the coded wire tag system, June 7-10, 2004.

TCCHINOOK. 1988. Chinook Technical Committee 1987 Annual Report. October 31, 1988.

Johnson, J.K. 2004. Regional review of coded wire tagging of anadromous salmon and steelhead in northwest America. Paper updated from 1989 to current year 2004.

Joint Coho DIT Analysis Workgroup. 2003. Analysis of coho salmon double index tag (DIT) data for the brood years 1995-1997. Northwest Fishery Resource Bulletin. Project Report Series No. 12. pp. 160.

Hankin, D. G. 1982. Estimating escapement of Pacific salmon: marking practices to discriminate wild and hatchery fish. Trans. Am. Fish. Soc. 111: 286-298

Lawson, P.W. and R.M. Comstock. 1995. Potential effects of selective fishing on stock composition estimates from the mixed stock model: applications of a high-dimension selective fisheries model. Oregon Department of Fish and Wildlife, Information Report. 95-2. Portland.

Lawson, P.W. and D.B. Sampson. 1996. Gear-related mortality in selective fisheries for ocean salmon. North American Journal of Fisheries Management. 10:512-520.

Morishima, G. 2004. In a nutshell: Coded wire tags and the Pacific Salmon Commission's fishery regimes for chinook and southern coho salmon. Background paper presented to Expert Panel for PSC Workshop on future of the coded wire tag system, June 7-10, 2004.

Morishima, G. and M. Alexandersdottir. 2004. Data Matrix. Requirements for assessment of fishery impacts on salmon stocks. Background paper presented to Expert Panel for PSC Workshop on future of the coded wire tag system, June 7-10, 2004.

Reimchen, T.E. and N.F. Temple. 2004. Hydrodynamic and phylogenetic aspects of the adipose fin in fishes. Can. J. Zool./Rev. Can. Zool. 82(6): 910-916

Rutter, L. 2004. Workshop background and charge to the panel. Paper presented at PSC Workshop on future of the coded wire tag system, June 7-10, 2004.

SFEC. 2002. Investigation of methods to estimate mortalities of unmarked salmon in mark-selective fisheries through the use of double index tag groups. TCSFEC(02)-1. pp.87

Weitkamp, L. and K. Neely. 2002. Coho salmon (*Oncorhynchus kisutch*) ocean migration patterns: insight from marine coded-wire tag recoveries. Can. J. Fish. Aquat. Sci. 59: 1100-1115.

Zhou, S. 2002. Uncertainties in estimating fishing mortality in unmarked salmon in mark-selective fisheries using double-index tagging. N. Amer. J. Fish. Man. 22: 480- 493.

PART III. JUSTIFICATIONS AND RATIONALE FOR EXPERT PANEL FINDINGS AND RECOMMENDATIONS.

MAJOR FINDINGS

In this section of our report, we provide the logic, justification and rationale for some, but not all, of our various findings and recommendations. The level of detail that we provide for individual findings or recommendations is a reflection of our perception of the complexity raised by a particular issue or by the novelty of an issue. Thus, for example, we devote considerable attention to the statistical issue of whether or not paired DIT releases can allow estimation of age- and fish-specific ocean exploitation (impact) rates and to the novel proposal for *full parental genotyping* (FPG) of hatchery salmon. In contrast, we devote little or no space to findings or recommendations that seem, to us, rather self-evident as, for example, *Finding 1*.

FINDING 1. *The CWT system is the only technology that is currently capable of providing the data required by the PSC's Chinook and Coho Technical committees. There is no obvious viable short-term alternative to the CWT system that could provide the data required for cohort analysis and implementation of PST management regimes for chinook and coho salmon. Therefore, agencies must continue to rely upon CWTs for several years (at least 5+), even if management agencies make decisions for development and future implementation of alternative technologies.*

FINDING 2. *Historic shortcomings of the CWT recovery data system remain problems today. These problems include inaccurate or non-existent estimates of freshwater escapement, especially stray (non-hatchery) escapement, and inadequate sampling of some fisheries (e.g., freshwater sport fisheries, direct sales).*

The CWT program consists of two major components, the tagging and the sampling programs. The parties to the PSC treaty have agreed to maintain a coded-wire tagging and recovery program designed to provide statistically reliable data for stock assessments and fishery evaluations. The sampling design of the CWT program is intended to ensure that these assumptions are met. Sample strata are defined by the agencies and sampling procedures designed to provide statistically reliable data. Quality control is the responsibility of each agency carrying out the tagging and sampling tasks within its jurisdiction.

A substantial effort is expended coast-wide annually for tag recovery programs in U.S. and Canadian commercial and recreational fisheries, in hatcheries, and on spawning grounds. Tag recoveries from returning adult coho and chinook salmon are on the order of 300,000 per year (Johnson, 2004.).

Unbiased estimation of tagged fish harvested or in escapement and estimation of exploitation rates requires that several basic assumptions be met, including:

1. Sampling in each stratum is random or representative.
2. The total harvest or escapement is known or estimated with no bias.
3. All fishery strata and all locations of escapement (hatcheries, spawning grounds) are sampled.
4. All tagged fish in the sample are correctly identified.

The basic design for the CWT sampling program is a stratified sampling design. Fisheries are stratified by type and, within each fishery type, individual strata are sampled by week, month or year. The definition of the spatial-time strata for sampling is determined by the conduct of the fisheries. The intent is that any fishery that exploits tagged salmon will be sampled at a known rate for CWTs. In addition, the sampling design calls for selection of samples from all escapement locations, including hatcheries and natural spawning grounds.

In practice, many of the basic assumptions (see Alexandersdottir et al. 2004) underlying use of CWT recovery data may often not be met:

> **Violation of Assumption 1.** In some commercial fisheries, e.g., Canadian troll, harvesters do not land catch at docks which can be easily accessed by samplers. Historically, freezer trollers removed the heads of salmon while at sea and sometimes did not retain all or any of them. However, vessels are now required to take the heads of adipose-clipped fish as a condition for obtaining a Canadian troll license – this was the case in NBC in 2004 and off WCVI beginning in 2005. If the number of heads collected does not agree closely with the number of adipose-clipped fish delivered, or the heads are not accompanied by specific recovery information (e.g., location and statistical week of capture), then CWT data obtained from these heads are of limited use. Bias in estimates of tagged harvest will result if boats which land at the docks, where their harvest can be sampled, are not targeting the same group of stocks as are the freezer boats.
>
> As another example, estimation of CWT catches among Canadian sport fishery harvests is based on voluntary returns. This approach assumes that the proportion of tagged harvest among voluntary returns is estimated for the sport fishery in an unbiased manner, that total harvest is estimated accurately, and that the voluntary recoveries provide an unbiased estimate of stock composition. This approach is thus different from the stratified random direct sampling of commercial fisheries.
>
> **Violation of Assumption 2.** Estimation of tagged harvest and escapement requires knowledge of sampling fractions, the fraction of the total catch or escapement in any particular stratum that is examined for adipose-clips and CWTs. Sampling fractions may not always be known, however, because totals are not always available, or estimates may be inaccurate and uncertain. If sampling fractions are unknown or missing or inaccurate, then estimates of total tagged harvest and escapement are biased. Two examples of this situation are identified below.

a. If some harvest is not reported, e.g., direct sales (sold by fishers "over the bank" or at the dock) or personal use without sale in commercial fisheries, then total harvest is not known. Direct sales or sales of eggs (without carcasses) are also a growing concern, especially as market prices for salmon meat plummet. Regardless of source, the failure to report (or sample) harvest results in negatively biased estimates of the total harvest for a stratum, positively biased estimates of the sampling fraction, negatively biased estimates of cohort size and positively biased estimates of exploitation rates.
b. Escapement estimates are not always available for all streams where tagged indicator groups are expected to be present or methods of estimating escapement are imprecise or biased. As fishery exploitation rates are reduced, the potential for bias in CWT analysis resulting from the failure to sample escapements becomes increasing important.

Violation of Assumption 3. Funding and staffing are sometimes insufficient to provide complete sampling coverage for fisheries and escapement.

a. Freshwater sport fisheries are not generally sampled for CWTs. An example of the sampling rates in Washington State fisheries is for the Puget Sound coho salmon brood years 1995-1997 discussed in the Joint Coho DIT Workgroup Report (2003). Table 5 below shows sampling statistics for Washington commercial and sport fisheries (not including the Columbia River) for coho salmon of these brood years. The marine fisheries, commercial and sport, are sampled at rates well over 20% when all harvest is totaled. Less than 10% of the total harvest is represented by fisheries which are not sampled. But terminal freshwater sport fisheries are, as a rule, not sampled for CWTs for coho or for chinook salmon.
b. Spawning grounds where tagged fish may be present are not consistently sampled. The Joint Coho DIT Workgroup Report (2003) included analyses for 17 double index tag coho salmon stocks; 6 out of these 17 stocks (35%) had no sampling of in-stream escapement. In additional streams there was insufficient or unreliable sampling. Overall, more than 50% of the streams had little or no escapement sampling where indicator tagged groups would be expected to be present.

Violation of Assumption 4. If the assumption that all tagged fish in the sample are correctly identified is violated, then estimates of tagged harvest or escapement will be negatively biased. During the years prior to mass marking, the adipose fin clip was used as an external indicator, but few studies were ever carried out to test the assumption that all adipose-clipped fish were correctly identified on return to hatcheries. An unpublished Canadian study (Alexandersdottir, pers. comm..) suggested that some hatcheries show a high percentage of missed clips, 15-25% , and there is some anecdotal information of tags missed in Skagit hatcheries. Where agencies have implemented ETD sampling, the rate of missed CWTs would be expected to be low as all tests of the equipment have shown a very low rate of missed tags when the equipment is used properly. Sampling on spawning grounds would also be subject to potential violation of this assumption as it would not always be possible to detect an adipose fin clip when spawning fish were in bad condition. However, if heads were taken from such fish due to apparent absence of

an adipose fin, most of these cases would lead to sampled heads with no tags, which would not be included as a tagged fish.

Table 5. Sampling statistics for fisheries exploiting coho salmon in Washington State (except Columbia River) for 1998-2000. Strata are fishery-periods.

Fishery type		1998	1999	2000
Commercial net and troll	Strata	341	260	376
	Harvest	184,129	161,787	452,598
	Sample	71,030	62,057	119,487
	% sample	39%	38%	26%
	Strata not sampled	135	103	162
	Harvest not sampled	13,028	13,219	37,315
	% not sampled	7%	8%	8%
Ocean Sport	Strata	27	59	55
	Harvest	25,713	47,491	83,829
	Sample	12,205	19,817	37,344
	% sample	47%	42%	45%
	Strata not sampled	3	5	7
	Harvest not sampled	296	300	498
	% not sampled	1%	1%	1%
Puget Sound Sport	Strata	66	45	53
	Harvest	62,456	18,697	77,910
	Sample	12,811	3,901	16,891
	% sample	21%	21%	22%
	Strata not sampled	25	11	4
	Harvest not sampled	922	558	154
	% not sampled	1%	3%	0%
Freshwater sport that impact Puget Sound coho salmon tag groups	Strata	24	24	24
	Harvest	15,824	15,457	23,509
	Strata sampled	1	1	1
	Sample	287	1,979	1,541
	% not sampled	98%	87%	93%
All Washington fisheries Combined (excl. Col. R.)	Total Harvest	288,122	243,432	637,846
	% not sampled	5.4%	5.5%	3.4%

Citations.

Alexandersdottir, M., Hoffmann, A., Brown, G. and P. Goodman. 2003. Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management. Presentation to Expert Panel, June 7-10, 2004 at Workshop on Future of the CWT Program: Challenges and Options

Johnson, J.K. (2004) Regional Overview of Coded Wire Tagging of Anadromous Salmon and Steelhead in Northwest America Paper updated from 1989 to current year 2004. Regional Mark Processing Center, Pacific States Marine Fisheries Commission.

Joint Coho DIT Analysis Workgroup. 2003. Analysis of coho salmon double index tag (DIT) data for the brood years 1995-1997. Northwest Fishery Resource Bulletin. Project Report Series No. 12. pp. 160.

FINDING 3: *Since the inception of the PST, the quality and quantity of CWT recovery data have deteriorated while increased demands have been placed on these data to provide guidance for protection of natural stocks at risk. Deterioration is due to a number of interrelated factors.*

The CWT program has been the primary source of data for assessing the impacts of fisheries on individual stocks of Chinook and coho salmon for over thirty years. Management regimes are based on constraining fishery exploitation rates and are driven by data collected from the CWT program to estimate stock-age-fishery specific exploitation rates. The trend over time in exploitation rates and marine survival indices estimated with CWTs, provides management agencies the information necessary for planning and evaluation of fishery regimes impacting Chinook and coho salmon salmon. For example, if the spawning return to a population suddenly declined, could the management agency attribute the change to changes in fishery impacts, reductions to marine survival, or a combination of these factors.

Figures 5 and 6 show exploitation rates and marine survival indices for Robertson Creek hatchery Chinook salmon since the 1973 spawning year (brood year) and the implementation of coast-wide sampling for CWT in 1975.

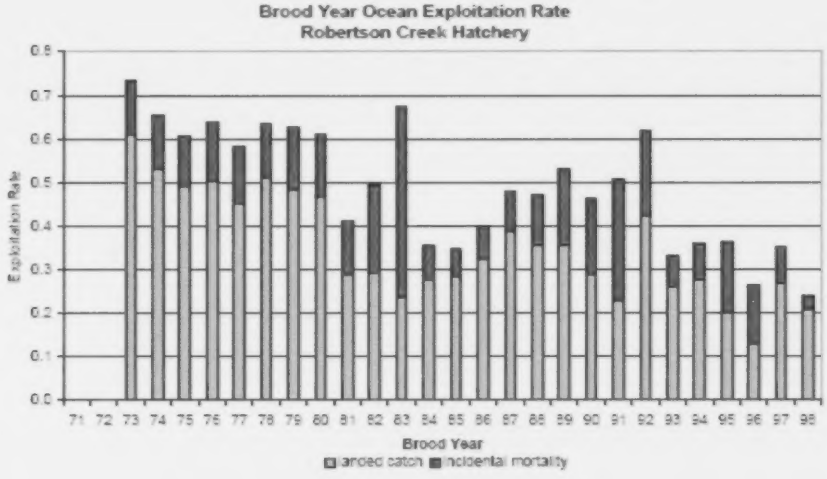


Figure 5. Estimates of exploitation rates on Robertson Creek Chinook salmon for brood years 1973-1998 (Taken from CTC 2004).

Exploitation rates have decreased over the time series (Figure 5) and marine survival has been highly variable and can change very suddenly (Figure 6). Figure 5 indicates that the proportion of total fishing mortality accounted for by landed catch has decreased over time and that recently the total mortality is less than 35% of the total production from a brood year.

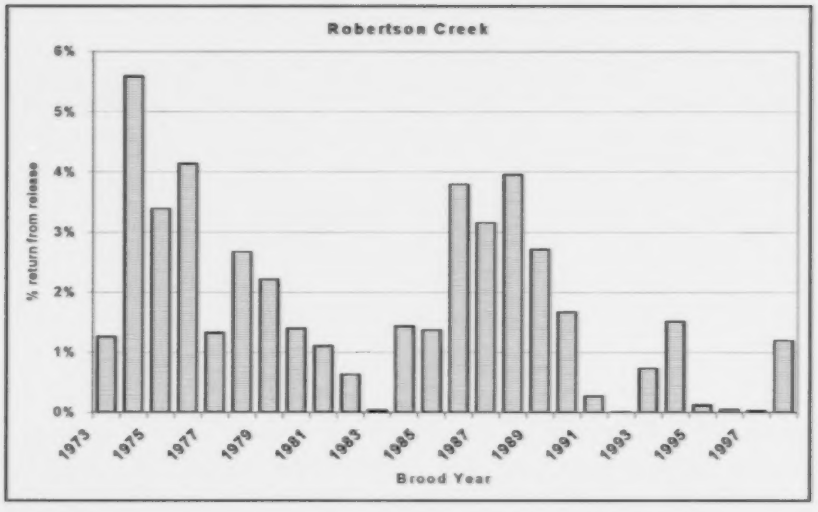


Figure 6. Estimates of marine survival index (total tagged return over total release) for Robertson Creek Chinook salmon brood years 1973-1998

Further, the reduction of fishery exploitation rates due to increasing conservation concerns for natural stocks of Chinook and coho salmon has resulted in fewer CWT recoveries in fisheries and more recoveries in escapements. For example, the estimated number of tagged fish in fisheries and escapement per 10,000 tagged fish released in the Green-Duwamish River in Puget Sound is shown in Figure 7, along with the percent of the tagged fish in escapement. For brood years 1971 through 1986 the largest proportion of the return was harvested in fisheries, but since then the escapement has generally had the larger percentage.

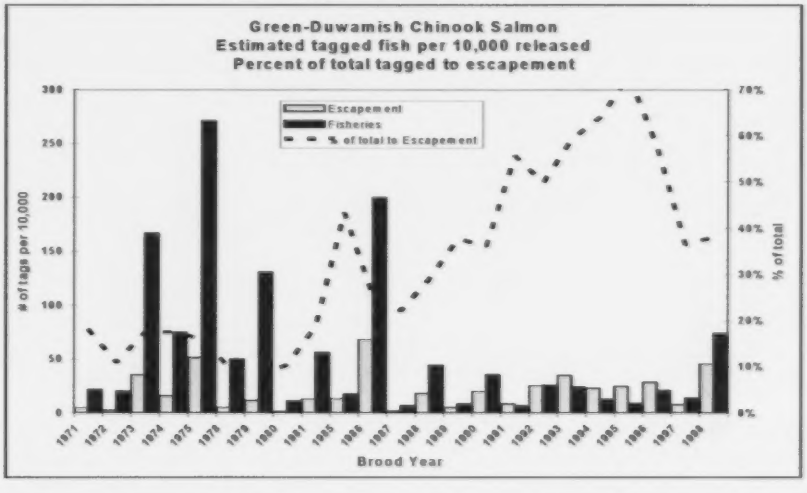


Figure 7. Number of tagged fish in fisheries and in escapement and percent of total in escapement for Soos Creek (Green-Duwamish hatchery) Chinook salmon for brood years 1971-1998.

With the reduced capability to recover tags from fisheries, increased mortality attributed to the unsampled incidental catch, and transfer of tags to the spawning escapements, the capacity of the CWT system to provide reliable data is deteriorating. A large part of the deterioration of the quality of data provided by the CWT system can be traced to the decreases in the number of tags recovered in fisheries and escapement, due to a variety of factors, include factors including:

- Fishery exploitation rates are being reduced and the number of tagged fish sampled in fisheries consequently decreased. As incidental mortalities increase there is a reduced access to tags. This decrease in sampled tags is even larger when marine survivals are depressed.
- Problems are surfacing with important components of the system, such as sampling rates in fisheries and escapements and reporting of catch and escapement accounting.
    - Agency budget pressures are reducing the capacity to monitor fishery catches and escapements, decreasing the number of tags recovered.
    - Alternative management approaches (e.g., non-retention regulations, mark-selective fisheries) are imparting different exploitation patterns on hatchery and wild fish and increasing the proportion of total fishing mortality of natural stocks attributed to non-landed mortalities that cannot be directly sampled.
    - Depressed markets are reducing the opportunity to sample catches due to: (a) "over the bank" sales; (b) removal of eggs for sale while leaving the carcass behind; and (c) processors and fishermen becoming increasingly reluctant to permit the snouts of fish to be removed for extraction of CWTs.

The precision of the number of tagged fish harvested and escaping, and consequently of the estimates of exploitation rate, is directly related to the number of CWTs recovered in fisheries and escapement. Precision increases (variance decreases) with increasing numbers of tags recovered in a fishery or in spawning escapement and can be usefully expressed as PSE (percent standard error = standard error of estimation/estimated value). Figure 8 shows the PSE of total tagged harvest or escapement as a function of number of recovered tags and was based on methods for estimating the variance of an estimated total (harvest or escapement) as described by Bernard and Clark (1996). The results shown in Figure 8 assume that total harvest (total escapement) is known with certainty. If there are errors of estimation of total harvest (or escapement), then the PSEs would be larger than those illustrated in the graph.[9]

[9] With a 20% sampling rate, the PSE will be over 30% with fewer than 10 tags recovered and does not fall below 20% until 20 tags are recovered; when 80 tags are recovered, the PSE falls below 10%.

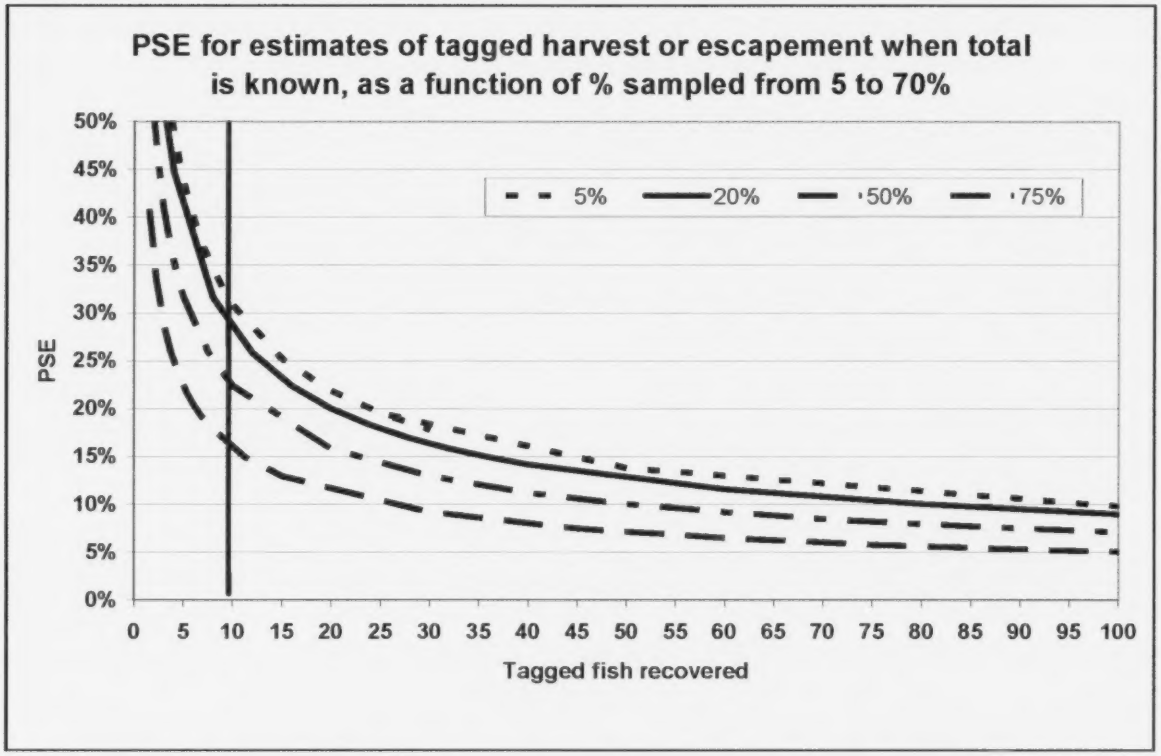


Figure 8. Estimated PSE of tagged harvest or escapement as a function of number of tags recovered and the sample rate.

Increasingly, management agencies are demanding more detailed information for planning and evaluation of fishery regimes impacting Chinook and coho salmon in response to conservation concerns for natural stocks. To address conservation concerns for natural stocks, fishery managers are pursuing planning models with finer time-area and stock resolution. As resolution increases, the number of tags present in each stock/time/area cell represented in the model will decrease, resulting in increased uncertainty in estimates of exploitation rates for each of these cells. This problem is discussed in the introduction to this report. Table 6 illustrates how the average number of tags recovered per year and the number estimated from these recoveries has changed over time for the Green-Duwamish Chinook salmon indicator tag group. All ages are combined and all fisheries occurring within each area and recovery type (e.g., net, hatchery) represented in the column headers. The freshwater fisheries, spawning grounds and hatchery recoveries are largely from the Green-Duwamish River. Each of the fishery cells in Table 6 represents multiple fisheries and four age groups; breaking these into fishery-age will result in very few tags per stratum. Few of these stratum will be represented by 10 or more tagged recoveries, which would provide a PSE of at least 30% (assuming 20% sampling).

Table 6. **Average number of tags recovered per year (Tags) and the number estimated (Exp) from these recoveries for the Green-Duwamish Chinook salmon indicator tag group for brood years 1971-1998. All ages and all fisheries occurring within each group represented in the column headers are combined.**

Brood Year	Commercial and Sport Fisheries								Spawning Grounds		Hatchery	
	Alaska		Canada		Washington		Freshwater					
	Tags	Exp	Tags	Exp	Tags	Exp	Tags	Exp	Tags	Exp	Tags	Exp
1971	7	19	8	33	6	18	62	121			165	179
1972	4	8	7	31	5	14	3	5			35	42
1973			31	138	21	56	2	6			690	713
1974			7	30	6	16					119	126
1975			34	139	12	34	15	20			341	401
1978	2	4	12	70	12	37	86	165			198	203
1979	1	4	10	53	10	30	54	95			135	140
1980			3	16	3	8	6	10			21	21
1981			10	42	8	24	30	82			266	272
1985			3	16	7	13	10	54	5	39	151	152
1986			21	109	38	89	101	297	18	112	1009	1,019
1987	2	4	3	13	3	6	10	25			39	39
1988	1	3	11	43	14	38	96	172	7	80	284	287
1989			4	14	3	6	22	37	2	20	54	55
1990	1	3	7	32	8	19	58	108	4	44	266	268
1991			1	4	5	12	16	28	1	18	110	113
1992	2	7	4	13	12	28	41	67	2	29	387	412
1993	3	5	5	14	8	19	20	33	4	63	267	483
1994	3	11	5	15	8	15	49	67	7	56	290	511
1995	5	15	2	4	3	7	51	62	7	67	207	271
1996	2	5	11	35	6	13	61	67	22	85	290	301
1997	1	1	5	22	4	14	45	70	6	10	129	129
1998	2	4	16	70	10	32	308	501	17	98	563	563

As regulatory constraints resulting from the ESA demand more accurate and precise estimation of the expected exploitation rate for listed populations, it may be unrealistic to expect that the CWT system, as it now stands, will have the capacity to meet the demands. Desired levels of certainty for modeling and regulation needs are not well defined, and this should be considered in evaluation of the future of the CWT system and developing a sample design that will meet the requirements set by management.

Citations.

Alexandersdottir, M., Hoffmann, A., Brown, G. and P. Goodman. 2003. Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management. Presentation

to Expert Panel, June 7-10, 2004 at Workshop on Future of the CWT Program: Challenges and Options

Bernard, D. R. and J. E. Clark. 1996. Estimating salmon harvest with coded-wire tags. Canadian Journal of Fisheries and Aquatic Science 53:2323-2332.

CTC. 2004. Annual Exploitation Rate Analysis and Model Calibration. PSC Joint Chinook Technical Committee Report. TCHINOOK (04)-4.

FINDING 4. *Fishery managers are becoming more concerned with obtaining information that cannot be readily obtained through direct observation or data provided by the CWT system. CWTs are not likely to be an effective tool to answer management questions that require identification of the origin of all fish encountered (e.g., stock-age composition of encounters of sub-legal sized fish) or the survival and migration routes of individual fish (e.g., migration patterns of released fish, catch-and-release mortality rates)*

An increasing proportion of fishery mortalities are being attributed to non-landed mortalities that cannot be directly quantified by sampling programs at the level of resolution required to estimate stock-age-fishery specific exploitation rates of fish that are not retained in the catch. Management measures such as catch quotas have led to non-retention restrictions, resulting in increased non-landed mortalities. This is illustrated in Figure 5 above, as exploitation rates decrease the relative contribution of non-landed mortalities to the total increases. Alternative management approaches, such as MM and MSF, are being employed to increase access to hatchery fish within allowable constraints on natural stocks and will increase the proportion of total mortalities that are not accounted for by landed catch. Methods for estimation of non-landed mortalities are currently a part of exploitation and cohort analysis.

The estimation of stock-age-fishery exploitation rates for fish that are not retained in the catch is problematic regardless of whether CWT or mitochondrial DNA technology is employed. For CWTs, each source of non-landed mortalities represents a source of additional uncertainty beyond the assumptions necessary to estimate recoveries using direct sampling (see discussion in Findings 2 above), and, as these represent a larger portion of the total exploitation, the potential bias also increases. For mitochondrial DNA based stock identification methods, large sample sizes and some means to distinguish fish from individual release groups of the same stock both within and between brood years would be required. Consistent methods to identify fish from individual releases would be needed to provide the raw data to estimate stock-age-fishery specific exploitation rates. For both methods, estimates of mortalities due to non-retention depend on critical assumptions, such as release mortality rates and drop-off, mark-recognition, and unmarked retention error, which are difficult to validate.

As the focus of fishery management becomes centered on conservation of natural stocks, the need for better information on migration routes and timing increases. Although useful information on stock incidence or composition might be obtained from genetic-based methods, data to estimate migration patterns and routes are extremely difficult to obtain through group mark-recapture experiments.

> These developments raise a crucial question: *"Is it realistic to expect the CWT system to be able to generate reliable estimates of stock-age-fishery specific exploitation rates for naturally spawning stocks of Chinook and coho?"*

If we continue to rely on the CWT system to sustain fishery regimes based on stock-age-fishery specific exploitation rates, the Panel should: (a) recommend specific measures to shore up the CWT data collection system; and (b) recommend that management regimes incorporate precautionary approaches to compensate for increased uncertainty (e.g., recommend that a

decision-theoretic approach be employed to establish allowable exploitation rates within a framework that explicitly considers the risk of error)

If it is unrealistic to expect the CWT system to provide necessary data to sustain fishery regimes based on stock-age-fishery specific exploitation rates, the Panel should recommend: (a) that the PSC consider specific alternative regimes along with data collection and monitoring systems required for implementation; and/or (b) specific data collection and monitoring systems to replace the CWT system.

FINDING 5. *Although there appears to be substantial empirical support for the critical assumption that exploitation rates and patterns of hatchery indicator stocks are the same as those of associated natural stocks, there are few peer-reviewed published studies on this topic, especially for chinook salmon. Much pertinent agency-collected data remain unanalyzed.*

Whenever patterns of CWT tag recoveries (e.g., age- and fishery-specific ocean exploitation rates) for marked hatchery fish are used to infer the probable recovery patterns of unmarked natural stocks of salmon, one must invoke an implicit assumption that tag recovery patterns of marked hatchery fish are the same as those for unmarked natural populations. For this assumption to be reasonable, it is critical that key life history attributes (run timing, age at maturity, size at age, ocean migration patterns) of hatchery and natural stocks match one another as closely as possible, and that hatchery release type and size at release match the smolt out migration pattern of natural stocks as closely as possible. For example, for chinook salmon CWT releases a fingerling release of hatchery fish in June may closely match the size and timing of out migration of a particular natural stock, whereas an October release of the same hatchery stock would out migrate at a much later date and a much larger size than an associated natural stock of concern.

Even when attributes of hatchery salmon are matched as closely as possible to those of associated natural stocks, it is extremely difficult to validate the assumption that exploitation rates and patterns for hatchery-origin releases can be used as surrogates for associated natural stocks. There have been very few direct tests of this assumption, largely due to difficulties in tagging sufficient numbers of natural stock smolts. In the ideal case, experimental validation could be achieved via joint release of a hatchery surrogate CWT group and application of CWTs to a large number of out migrating smolts from the natural stock of interest. Although in principle the design of such a study is straightforward, in practice: (a) it is difficult to tag a sufficiently large number of natural smolts; and (b) tagging and handling mortality may be high for tagged natural smolts.

Our Panel members developed the following overview of information available to test the assumption that hatchery indicator stocks share the same exploitation history as their natural stock counterparts.

Alaska. In Southeast Alaska, ADFG collects and coded-wire tag wild chinook and coho. For chinook, projects collect wild smolts and implant CWTs and release tagged fish in the following rivers on an on-going basis: Taku, Stikine, Chilkat, Chickamin, and Unuk. Similar studies have been carried out on a less regular basis in several other rivers. We also have chinook hatcheries that release fish with CWTs and brood stock used comes from Andrew Creek (Stikine) and the Chickamin. ADFG staff have done some comparisons of hatchery and wild coded wire tag recoveries. Unpublished results suggest that hatchery fish may have higher harvest rates because they tend to remain in the inside waters of Southeast Alaska for longer times than wild fish and thus are more susceptible to being caught in fisheries than are the wild fish that tend to spend more of their marine life in offshore waters and away from fisheries (S. McPherson, ADFG, unpublished analyses). For coho, ADFG has long term data on CWT returns for wild vs. hatchery CWT fish, but it does not appear that comparisons of catches and returns for the wild and hatchery fish have been made. There are four stocks of wild coho that have been

continuously tagged over a period of better than 20 years as well as long term CWT data for a variety of hatchery stocks of coho in SEAK.

British Columbia. The most common field tests of this assumption have involved coho salmon because the necessary numbers of wild smolts can be collected and the large size of smolts allows safe handled. For fall chinook salmon, the handling mortality is very high and many agencies do not encourage tagging of the natural fall chinook. There is empirical evidence that tagged hatchery coho and tagged natural coho have very similar exploitation patterns and rates and that variation in marine survival rates also covary. One the first direct comparison of hatchery and wild coho was reported by Schubert and Lister (1986). Tagging of wild and cultured Salwein Creek coho showed no difference in catch distribution, or size of the fish in catches and the spawning escapement. Also, the Canadian Department of Fisheries and Oceans has conducted extensive tagging of hatchery stocks and wild 'indicator' stocks in the Strait of Georgia and lower Fraser River since the mid-1990s. Data for three hatchery stocks and two wild stock indicators are compared in the Figure 9 below. The data presented in these charts are from Simpson et al. (2002) and available on the CDFO website[10]. These data demonstrate the close similarity of harvest rates between the hatchery and wild tagged groups but greater variation between stocks and years in marine survival rates. These results are typical of how the indicator stock data are used. Survival rates of hatchery stocks are not assumed to be equal with the natural stocks but they do tend to covary. A more in depth analysis of these data has been presented by Labelle et al. (1997).

Assessing this assumption for chinook salmon is more difficult and is usually inferred by similarities in survival variations and age structure in terminal runs. For example, the time series of coded-wire tag programs at Robertson Creek and Chilliwack River hatcheries provide the basis for CDFO's method for forecasting the terminal runs of west coast of Vancouver Island fall chinook and for the Harrison River chinook, respectively. These methods have been extensively reviewed by Canada's PSARC (Pacific Scientific Advisory Review Committee; http://www.dfo-mpo.gc.ca/csas/) and the Chinook Technical Committee of the PSC. For a description of the method based on exploitation rate analyses of coded-wire tagged hatchery stocks and its relation to age-structured returns of local natural populations, see Riddell et al. (2002).

[10] www.dfo-mpo.gc.ca/csas/Csas/DocREC/2002/RES2002_094e.pdf

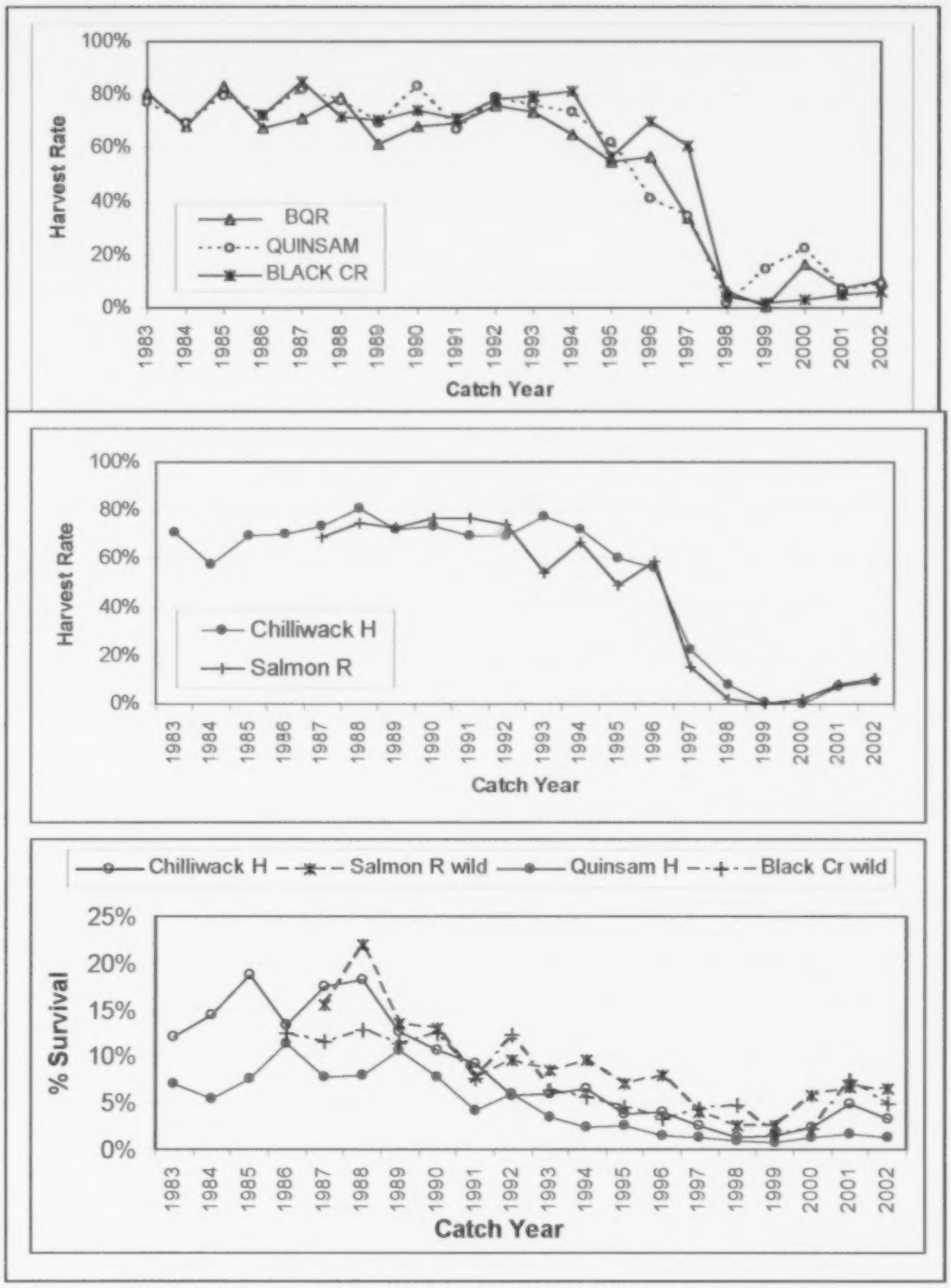


Figure 9. **Total harvest rates and marine survival rates for Hatchery (Big Qualicum, Quinsam, and Chilliwack) and 2 wild (Black Creek and Salmon River) coho indicator stocks in the Strait of Georgia, B.C.**

Washington. Four indicator stocks from Western Washington are derived from wild brood stocking efforts. Since wild chinook smolts are too sensitive to capture and tag, the intent is to mark a group that represents wild fish to the best extent possible. In these studies, wild adult chinook spawners are captured and brought into a hatchery for spawning. The subsequent progeny are incubated, reared, and tagged with coded wires. After tagging, the fish are transferred to an imprinting pond adjacent the native river, where the fish are released at a size and time consistent with the wild chinook migration. Indicator stock programs include: Skagit River Summer Chinook Indicator Stock Study (Skagit System Cooperative); Stillaguamish River Native Chinook Indicator Stock Study (Stillaguamish Tribe); Hoko River Fall Chinook Indicator Stock Study (Makah Tribe); Queets River Wild Fall Chinook Indicator Stock Study (Quinault Indian Nation). One wild coho indicator stock study is conducted by the Quinault Indian Nation on the Queets River. Wild coho smolts are annually captured and tagged to provide an indicator stock of naturally-produced coho salmon from the north Washington coast. All of these projects include spawning surveys to estimate escapement and recover CWTs.

Although the PSC Coho TC did not perform statistical pair wise comparisons of Hatchery Wild (H/W) experiments, the Committee found strong clustering of H/W stocks when it developed procedures for estimating stock compositions of coho fisheries (TCCOHO 1989). A comparison of H/W distribution patterns for BY84-89 Skagit coho also found no significant differences (Bob Hayman, Skagit System Cooperative, pers. comm.).

Ppublications that deal, at least in part, with validation of this critical assumption include:

Everson, D.F., D.R. Hatch, and A.J. Talbot (undated). Hatchery Contribution to a Natural Population of Chinook in the Hanford Reach of the Columbia River, Washington. Columbia River Intertribal Fish Commission. Portland, OR.

Labelle, M., C.J. Walters, and B. Riddell. 1997. Ocean survival and exploitation of coho salmon (Oncorhynchus kisutch) stocks from the east coast of Vancouver Island, British Columbia. Can. J. Fish. Aquat. Sci. 54: 1433-1449.

McClure, M.M. 1999. Ocean fishery distribution of hatchery versus wild coded-wire tagged fall chinook from the Hanford Reach. Columbia River Intertribal Fish Commission. Portland, OR.

Riddell, B.E., W. Luedke, J. Till, S. Taylor, A. Tompkins. 2002. Review of 2001 chinook returns to the west coast Vancouver Island, forecast of the 2002 return to the Stamp River/Robertson Creek Hatchery indicator stock, and outlook for other WCVI chinook stocks. CSAS Res. Docu. 2002/119.

Schubert, N.D., and D.B. Lister. 1986. A Comparison of the Catch Distribution, Harvest Rate and Survival of Wild and Cultured Salwein Creek Coho Salmon. Canadian Technical Report of Fisheries and Aquatic Sciences 1425.

Simpson, K., D. Dobson, S. Lemke, R. Sweeting, R.W. Tanasichuk, and S. Baillie. 2002. Forecast for southern British Columbia coho salmon in 2002. CSAS Res. Docu. 2002/094.

Stopha, M. 2000. Production, Contribution, and Catch Timing of Hatchery Coho Salmon With Comparisons to Wild Coho Salmon in Southeast Alaska Commercial Fisheries. Regional Information Report 1J001-12. ADFG, Division of Commercial Fisheries Southeast Region, Juneau, AK. February 2000.

TCCOHO 1989. Report to the Southern Panel on Coho Stock Composition Estimates in the Southern Panel Area. TCCOHO(89)-1. September 29, 1989.

Weitkamp, L., and K. Neely. 2002. Coho salmon (Oncorhynchus kisutch) ocean migration patterns: insight from marine coded-wire tag recoveries. Can. J. Fish. Aquat. Sci. 59: 1100-1115.

FINDING 6. *The Panel concurs with previous ASFEC findings that Mass Marking (MM) and Mark-selective Fisheries(MSFs) together pose a serious threat to the integrity of the CWT recovery data system. In particular, under MSF, recovery patterns for adipose-clipped fish are no longer suitable indicators of recovery patterns for unmarked natural stocks, and under MM there are significant practical and statistical issues raised by the need to find adipose-clipped and coded wire tagged fish (Ad+CWT) from among the much larger number of fish released with adipose clips only. As MSF increase in number and intensity, the discrepancy between the fates of adipose-clipped fish and untagged fish will increase. The seriousness of these threats was pointed out to the PSC as early as 1991 in a memo reproduced as a frontispiece for this report.*

MM and MSF together present several obvious and serious threats to the integrity of the CWT tag recovery system:

1. The explicit intention of MSFs is to allow fishermen to capture larger numbers of marked hatchery fish, which can withstand greater overall exploitation rates than unmarked natural stocks. As noted in Finding 5, exploitation rates and patterns of marked CWT surrogate release groups have always been assumed to be the same as those of unmarked natural stocks of interest, but this assumption has been rarely validated even when unmarked natural stocks are subjected, theoretically, to the same fisheries as marked (adipose-clipped) CWT hatchery release groups. When marked fish are subjected to mark-selective fisheries in which all unmarked fish captured must be released, marked and unmarked fish will always be subjected to different exploitation rates and patterns except for the uninteresting case when non-landed (catch-and-release) mortality is 100%. Thus, MSFs, by themselves, invalidate the assumption that marked CWT releases of hatchery fish are subjected to the same exploitation rates and patterns as associated unmarked natural stocks.

2. An explicit objective of MM (release of very large numbers of hatchery salmon with identifying adipose fin clips but without CWT) is to allow greater harvest of marked hatchery fish in mark-selective ocean and/or freshwater fisheries. Unfortunately, this practice is at odds with the historic inter-agency agreements to "sequester" the adipose fin clip as an external mark to be used exclusively for identification of fish with CWT. When the adipose clip is used as a mass mark, at least two undesirable consequences result from the perspective of the existing CWT program:
    a. Much larger numbers of adipose fin-clipped fish will be captured in fisheries but they can no longer be automatically expected to carry CWTs. At great practical and financial expense, heads may be taken from all sampled adipose-clipped fish in fisheries or, alternatively, expensive electronic systems (portable wands or fixed location tubes) may be used to electronically screen adipose-clipped fish for presence of CWTs before heads are taken. Either response makes sampling of fisheries for tagged fish more expensive, more time-consuming, and more subject to errors of identification of fish belonging to CWT groups.
    b. The additional obligations and costs for sampling identified in 2a, above, may cause some agencies to reduce sampling fractions in ocean fisheries so that total outlays for ocean sampling will not be substantially increased as a consequence of mark-selective fisheries. If so, uncertainty in estimation of CWT recoveries in all ocean fisheries may be increased (see also justification and Rationale for Finding 3).

3. When MSFs account for only a very small fraction of total ocean or freshwater fishery landings of a particular hatchery stock, non-landed mortalities of unmarked fish belonging to an associated natural stock will not have much impact on the total mortalities experienced by this natural stock. In this case, uncertainties in estimation of non-landed mortalities for a natural stock would have little impact on overall uncertainty in estimation of total mortalities of the natural stock. If and when the number and intensity of MSFs increases so that they account for a substantial fraction of total ocean or freshwater fishery landings of a particular hatchery stock, however, then total mortality rates experienced by an associated natural stock of concern would theoretically be less, perhaps much less, than those experienced by the marked hatchery stock. The degree to which the total mortality rates experienced by the hatchery and associated natural stock would differ would depend on the number and intensity of MSFs and on non-landed (catch-and-release) mortality rates to unmarked fish in the MSFs. The number and magnitude of MSFs will be known, but the non-landed mortalities rates will generally be unknown and may depend on fish size and age and may vary across fisheries.

FINDING 7. *For both coho and chinook salmon, it appears possible to generate approximately unbiased estimates of* total *non-landed mortalities at age in all MSFs from a full age-structured cohort analysis of paired Double Index Tagged (DIT) releases of CWT groups. The accuracy of these estimated total non-landed mortalities may be poor unless very large numbers of fish are released in DIT groups. Estimates of total non-landed mortalities in all MSFs combined would not, however, meet requirements of current PSC regimes to estimate age- and fishery- specific exploitation rates.*

a. *There does not appear to be any unbiased method to allocate an estimate of total non-landed mortalities over a set of individual mark-selective fisheries. That is, overall non-landed mortality impacts may be unbiasedly estimated, but impacts in individual MSFs may not be.*

In Appendix A, we present a proposed method that allows nearly unbiased estimation of *total mortalities at age* in all MSFs for an unmarked hatchery stock subjected to a mixture of non-selective and MSFs. This proposed method is based on analysis of estimated CWT recoveries for a single cohort of chinook salmon that is released using the DIT protocol: one group of fish is released with an identifying external mark and CWT code, and a second group of fish is released without an identifying external mark but with a distinctive CWT code. The logic of the method is based on the reasonable supposition that the age-specific freshwater escapements of fish belonging to the two DIT groups should carry a strong signal of the differential fishery impacts between the two groups. For simplicity, assume that both DIT groups are of identical size at release. At age 2, escapements for the two groups should be essentially the same as fish from both groups should generally be below minimum size limits and released, if captured, in ocean fisheries. At age 3, the escapement at age for the unmarked group should be greater than that for the marked group because the marked group are subjected to landings in MSFs whereas unmarked fish are only subjected to the (presumably lower) non-landed mortalities in MSFs. At ages 4, 5 and 6, the differences between escapements of the two groups should become progressively greater as the cumulative mortalities to the marked fish should be progressively greater than the cumulative mortalities to the unmarked fish. Although estimation of total non-landed mortalities at age would allow estimation of total fishery-related mortalities at age and/or over a cohort's life, current PSC fishery management regimes require that age- and fishery-specific exploitation rates (or non-landed mortality impact rates) be estimated in individual fisheries.

Estimation of non-landed mortalities at age of unmarked fish in individual mark-selective fisheries is generally impossible unless one is willing to make a number of assumptions concerning fish movements, fishing pressure or fishery harvest rates, and/or non-landed (catch-and-release) mortality rates that in many cases may be unrealistic or invalid. At the end of Appendix A, we present some possible approaches for estimating non-landed mortalities in individual mark-selective fisheries if one were willing to make specific simplifying assumptions which may or may not be reasonable.

When salmon are subjected to a mixture of non-selective and selective fisheries that may operate in different locations, but at essentially the same time, analysis, and interpretation of CWT recovery data, especially estimation of non-landed mortalities in specific MSF, is complicated by the spatial distribution and heterogeneity of a particular stock. That is, in a particular week at a particular location, only some fraction of a stock may be available for capture. The spatial

distribution of the stock in the next week will depend on movements of fish between weeks and on removals that took place at particular locations during the previous week. In Appendix B, we present a brief treatment of how movement and/or segregation affect ability to estimate non-landed mortality rates in mark-selective fisheries.

FINDING 8. *We have serious methodological and sampling concerns regarding application of the DIT concept:*

b. *We have been unable to find convincing theoretical or empirical evidence that Double Index Tagging (DIT) approaches can generate precise, unbiased estimates of age-fishery-specific exploitation rates for natural stocks of chinook or coho salmon (represented by unmarked DIT release groups) in the presence of sub-stocks and multiple mark-selective ocean fisheries. Methods for analysis of DIT recovery data remain incompletely developed for: (a) complex mixtures of non-selective and mark-selective fisheries with varying exploitation rates and different catch-and-release mortality rates, and (b) the full age-structured setting required for chinook salmon.*
c. *The potential utility of DIT is undermined by the reluctance of some agencies to recover CWTs for both marked and unmarked DIT groups. This reluctance can be attributed in part to the additional sampling burdens and costs associated with the use of the adipose fin clip both as a mass mark and as a visual indicator for the presence of a CWT.*

FINDING 9. *Concerns have been raised regarding "reliability in practice" of electronic wanding of salmon (especially large chinook) for presence of CWTs, but empirical evidence brought to our attention has consistently suggested that electronic wanding detection of CWTs is very reliable. Problems reported with electronic wanding appear to be operational in nature, centering on purchase and maintenance costs of equipment, availability of back-up detection equipment, training and supervision, increased sampling costs, etc.*

FINDING 10. *Based on recent proposals, many chinook and coho salmon stocks affected by PST regimes may be impacted by increasingly complex mixtures of non-selective and mark-selective fisheries. The overall impact of MSF's will be stock-specific, depending on migration and exploitation patterns. The potential complexity of these fisheries and the limitations of exiting assessment tools have significant ramifications for fishery management:*

a. *Management agencies have not provided a framework to address the increased uncertainty that would result from the initiation of significant MSF's;*
b. *Improved coordination of sampling and analysis will be required to maintain stock assessment capabilities.*

FINDING 11. *Some existing technologies can complement the existing CWT system. These technologies include at least otolith thermal marking and Genetic Stock Identification (GSI) methods.*

OTOLITH THERMAL MARKING – An Overview of the Technology and Consideration of its Potential Applications for Management of PSC Salmon Fisheries

Otolith thermal marking is a widely used technique for identifying hatchery-released salmonids by inducing structural patterns in their otoliths using short-term water temperature manipulations. The method provides a practical means for 100% marking of hatchery salmon populations, and offers some distinct advantages over individual tagging of fish. Large-scale thermal marking programs occur in Canada, Japan, Russia and the United States, with more than 1 billion juvenile, primarily pink and chum, salmon marked annually. This overview is based substantially on an upcoming text chapter (Volk et al. 2004) and we thank Eric Volk for providing a prepublication copy. We review several aspects of otolith thermal marking, including the basis for inducing structural patterns into otoliths with water temperature changes, strategies for creating mark codes, and error rates in mark recovery. We also consider coordination difficulties inherent in trying to recover such marks in mixed stock ocean salmon fisheries.

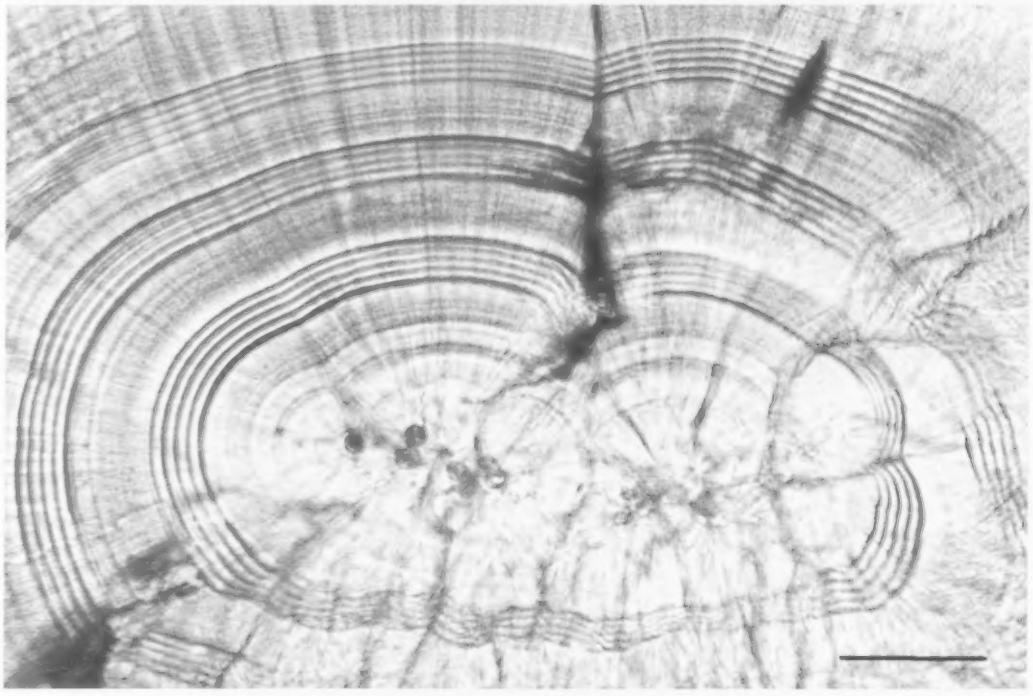
Inducing otolith marks

Otoliths are primarily (~95%) composed of calcium carbonate (usually in the form of aragonite), an array of trace elements, and an organic protein which functions as a template for the deposition of calcium carbonate. Although organic matrix is distributed throughout the growing otolith, the characteristic dark and light bands observed in sectioned otoliths reflect the bipartite nature of otolith increments, each consisting of a calcium rich component, translucent when viewed with transmitted light, and an organically rich component, optically dense under transmitted light. Nomenclature refers to the organically rich portion of otolith increments as D-zones, or discontinuous zones, and the translucent portion, dominated by crystalline calcium carbonate, as L-zones or incremental zones. Otolith thermal marks consist of a particular pattern consisting of several otolith increments and corresponding dark (D-zone) or light (L-zone) zones.

The basis for otolith thermal marking rests in the fundamental relationship between environmental temperature fluctuations and the appearance of regularly deposited otolith increments. The idea behind using short-term temperature manipulations to mark juvenile fish otoliths is to alter the appearance of D- and L- zones in one or more increments to produce an obvious pattern of events. A regular series of extended warm water events alternating with cooler, ambient water can create very clear patterns on otoliths.

An important aspect of inducing patterns on otoliths with periodic water temperature manipulations is an appreciation of the ambient thermal regime's impact on increment characteristics, against which induced patterns must be recognized. Otolith mark recognition can be thought of as a signal-to-noise ratio problem where the induced mark signal must be distinguished against the background incremental "noise" created by the ambient thermal regime.

When ambient temperatures are relatively uniform with little diurnal or short-term fluctuation, otolith increments will typically be poorly contrasted and even small temperature change effects on increments will be obvious against this background. When ambient thermal regimes fluctuate and produce highly contrasted otolith increments with dark D-zones, however, much more dramatic temperature changes are necessary to make induced increment effects stand out against background otolith banding patterns. If one uses a sufficiently large temperature decline or increase lasting at least 24 hours, most background structural noise can be overshadowed by the deliberate mark event. An example of the type of marks that can be produced using otolith thermal marking is shown in the picture below.



Thermal marks in the sagittal otolith of a juvenile Chinook salmon. Three sets of five events each were induced into the pre- and post-hatch regions by daily exposures to cooler water for 8 hr followed by a return to constant temperature, ambient water. Scale bar at lower right bottom = 50 µm. Reproduced from Volk et.al. 2004.

Organizing Pattern Information

The selection of a pre-determined schedule of temperature changes to induce otolith marks depends upon the goals of a study or application, but also helps avoid the problem of spurious events confusing the distinction between marked and unmarked fish.

Hatchery-incubated salmonids are particularly well-suited for thermal marking because incubation and yolk absorption stages are protracted, large numbers of fish are concentrated in these facilities, and otoliths begin growing in embryos. As a result, there is a lengthy period

during which multiple marks may be administered, including the pre- and post-hatch otolith zones. The frequent occurrence of an otolith "check" mark associated with hatching in salmonids conveniently separates these two regions and provides an opportunity to encode different information in each region. However, applications of otolith thermal marking for identifying salmon stocks in the North Pacific have grown enormously in the past decade, and it has become clear that systems for organizing information on the otolith are necessary to avoid mark duplication.

Systems for inducing and describing thermal mark use induced band number, relative spacing between bands, and the position of groups of induced bands relative to one another in specific otolith regions to encode information. In theory, there are truly an enormous number of patterns available, given the time needed to induce marks and the space available on otoliths to do so. Practical limitations associated with hatchery operations, fish development and visual recognition, however, may place important limits on the actual number of available patterns (Hagen, 1999) and growing number of stocks being marked on an annual basis in the North Pacific has created some potential mark duplication between countries and fish stocks (Urawa et al., 2001). Apparent conflicts can often be resolved through inspection and measurement of the otolith mark image. According to Volk (2004), the number of distinctive otolith marks that may be realistically produced for juvenile coho and chinook salmon at production-type salmon hatcheries may be as small as 200-250 (Volk comments at CWT Workshop), but Volk (pers. comm.) is exploring this issue further. The maximum number of distinct marks that can realistically be produced for chinook salmon is likely no more than 1,000.

Errors in mark recovery

Volk et al. (2004) report a number of published studies which have attempted to establish error rates of identifying otolith marked fish and separating them from unmarked controls. Reported error rates in these studies have been highly variable, although Volk (1994) reported very low error rates and near perfect recognition of ten different otolith patterns among juvenile chinook salmon and Volk et al. (1999) report very low error rates (2%-6%) among adult chinook and coho salmon of known stock origin. Generally, false positives (apparent otolith mark for unmarked fish) seem more frequent than false negatives (no mark identified for marked fish) and higher error rates appear to be associated with poor mark quality (e.g., poor control of exposure duration and/or temperatures during mark induction).

Unfortunately, it is difficult to interpret the relevance of these studies of published error rates in a potential practical mixed stock fishery application where, say, 10 component thermally marked hatchery stocks might be mixed with 20 unmarked stocks. In such contexts, conclusions are usually reached by consensus among multiple readers. Statistical measures such as the *kappa* statistic (Blick and Hagen 2002) may be used to measure reliability of determinations between two independent readings, but they cannot establish the accuracy of stock assignments. Independent readers could, for example, consistently misidentify unmarked fish from a particular natural stock as bearing the otolith mark from a specific hatchery stock.

Applications

Volk et al. (2004) report numerous successful and practical fishery management applications of otolith thermal marking. These applications range from simple applications (using otolith thermal marks to distinguish wild and hatchery fish from the same stock on their return to freshwater) to much more complex applications (assessment of stock origin in mixed stock ocean fisheries studied by the North Pacific Anadromous Fish Commission).

When mark rates are near 100% for hatchery stocks and individual hatchery stocks comprise a substantial fraction of ocean abundance, the proportional contribution of such hatchery stocks can theoretically be estimated with high precision from a fairly small sample and there is the opportunity for rapid (say, overnight) turnover. For example, continued use of otolith thermal marking in the Prince William Sound pink salmon fishery has apparently demonstrated that greater precision of hatchery contribution estimates can be obtained with far smaller sample sizes and at much greater speed than could have been provided from traditional CWT programs (Joyce and Evans, 2001).

Conclusion

Thermal marking has been successful with a variety of salmonid species and Canada, Japan, Russia and the US are currently thermally marking about 20% of hatchery-produced salmon in the North Pacific Ocean (Urawa et al., 2001). An estimated 1.1 billion thermally marked juveniles were released from Pacific Rim hatcheries in 2003, more than 90% of which were pink and chum salmon.

Like any marking method, there are also drawbacks associated with otolith thermal marking. Primary among these is the need to modify existing hatchery infrastructure in order to deliver thermal events to incubating fish. This involves considerations of power supply, water availability and space, important and potentially limiting resources in a fish culture facility. Otolith marking may also require some level of detailed scheduling of thermal events where a number of different codes must be induced among fish fertilized on different dates. Also, we do not have complete control over the recording of information within the otolith and environmental perturbations occurring around the marking schedule may be recorded, producing confusion and possible errors on recovery. As a result, it is important to use post-marking "voucher" otoliths to document the actual pattern produced. Also, otolith thermal marking requires lethal sampling which precludes its use in some circumstances.

In an attempt to document and coordinate the widespread application of otolith thermal marks, a salmon marking working group was established under the Committee for Scientific Research and Statistics of the North Pacific Anadromous Fish Commission (Urawa et al, 2001). This group maintains a (website) database of existing thermal marks and attempts to coordinate mark induction to avoid duplication. In principle, countries annually submit specific mark plans for induction to the upcoming brood year, so that obvious conflicts might be resolved prior to the commencement of marking. Following the marking season, summaries of actual marks induced are submitted and entered into the database. Specific information on each nation's mark groups and induced patterns is summarized, including a digital image of most mark patterns. This

website database provides a ready source of information for determining the origins of an unknown pattern. The long-term utility of the otolith marking technique depends upon participatory oversight among its users.

The most serious limitation of using otolith marks for management of in mixed stock ocean fisheries under the PSC's jurisdiction is the small number of distinct patterns that can be reliably distinguished (perhaps as small as 200-250 and probably no more than 1,000) as compared to the total number of identified runs and races of fish captured in waters over which the PSC has jurisdiction. Thus, potential for use of otolith thermal marks for ocean fishery analysis is problematic whereas potential for in-river use of otolith marks to separate a limited number of runs from the same river system is excellent.

Genetic Stock Identification Methods (GSI)

There are several ways that genetic information might contribute to management of Treaty fisheries. The first is the use of molecular genetic data in genetic stock identification (GSI). Genotypic data from molecular markers can assign individual fish to stock of origin with high confidence. This requires a population genetic "profile" for each potential stock of origin, which is frequently referred to as a baseline dataset. The baseline is generally a set of population specific frequencies for alleles (variants of the same gene) from a group of variable genes. Then, in so-called "mixed fishery analysis", a sample of individual fish is taken from a test fishery, or sometimes in a fishery-dependent manner (through at-sea or port sampling), and genotypes from these fish are determined. These genotypes are compared with the baseline using a statistical procedure and yield the most probable stock of origin for each individual fish. This is then expanded into estimates of the stock proportions in the fishery. Such sampling can also be performed in stream in larger river systems with multiple stocks, to estimate stock-specific escapement.

GSI has a long history in salmonid fisheries, with protein electrophoresis (allozymes) used to discriminate divergent natural and hatchery stocks of trout more than 20 years ago. More recently, the use of highly variable molecular markers, such as microsatellite loci, has allowed discrimination and identification of individuals from closely related stocks, as well as the simultaneous evaluation of multiple hypotheses about potential population of origin.

Several speakers at the PSC-CWT Workshop described for the Panel some of the current microsatellite datasets available for GSI in chinook and coho salmon, as well as analytical methods and procedures currently used in applying such data to fishery management. Panel members heard about one of the most extensive GSI applications to date in the use of a Canadian baseline dataset and "real-time" evaluation of mixed fishery samples for pre-exploitation regulation of fishing regimes for chinook salmon off of British Columbia. Such "real-time" GSI has promise for dynamic management and allocation of fishing effort to different stocks of genetically distinguishable fish.

It is important to note that GSI provides a different type of data than does the CWT program and using GSI as a replacement for CWT analysis would necessitate a fundamental shift in the models with which the fisheries are managed. Current GSI methods provide estimates of stock

proportions in a fishery sample, but do not provide a simple way to translate this into exploitation rate for cohort reconstruction. GSI provides an estimate of the relative probability that every individual fish originated in each of the sampled populations included in the baseline. A dense GSI sampling regime could potentially be used to estimate exploitation rate if the indicator stocks were included in the baseline and release estimates were obtained in some other way. Such a method would not provide an *a priori* way to identify fish from indicator stocks, but would require genetic analysis of a relatively large, random sample of fish, some proportion of which would be allocated to the indicator stocks through genetic analysis. Advantages of such a GSI application are that it would provide information on exploitation of wild populations and would eliminate problems associated with tag loss, tag recovery and blank tags. Disadvantages would include the loss of individual-specific information about release date (and therefore age), the necessity to survey more fish than is currently the case to provide an equivalent sized sample for estimate of indicator stock exploitation rates and the costs associated with such expanded analysis. Another issue of concern in current GSI applications, which is readily addressed with available statistical methods, is that every fish in a mixed fishery analysis is assigned to a population in the baseline. This means that if the fish originates in an unsampled population it is still allocated to a sampled population, which may be completely unrelated (but which will usually be the one with the smallest genetic distance to the true population of origin) and demographically independent. The correct approach is to use a likelihood criterion to assess the strength of assignment and not assign fish with low likelihood, allocating them to unsampled populations. Most applications of GSI to date have not employed this approach, although there are several pieces of freely available software that perform such assignment analyses (e.g., Structure, BayesAss+, GeneClass). Pieces of software that do not use such an approach include the primary software currently used for stock proportion estimation, SPAM, and assignment programs WhichRun and DOH.

Genetic data also offer the ability to more closely estimate fishery impacts on wild stocks. One assumption of the CWT program is that the hatchery indicator stocks are representative of the associated wild stocks because of similar ancestry, release time and release site. However, the extent to which this is true is unknown for chinook salmon and has only been partially demonstrated for coho salmon. Moreover, the effect of mark-selective fisheries on this assumption is not known, but is likely substantial. Genetic methods offer the ability to assess wild stocks directly, because GSI can include both hatchery and wild (clipped and unclipped) fish and information from GSI mixed fishery analyses can then provide allocation of stock proportion to either the wild, hatchery or the aggregate hatchery/wild genetic component of a stock.

Combining CWT Recovery Data with Otolith Thermal Marks or GSI Information

In Appendix C we present an example of a potential use of GSI information to complement information obtained through CWT recovery data and thereby generate an estimate of freshwater escapement for natural stocks of salmon for which direct estimation of freshwater escapement may be problematic or impossible.

Citations

Blick, D.J., and P.T. Hagen. 2002. The use of agreement measures and latent class models to assess the reliability of classifying thermally marked otoliths. Fishery Bulletin 100: 1-10.

Hagen, P. 1999. A modeling approach to address the underlying structure and constraints of thermal mark codes and code notation. NPAFC Doc. 395. Alaska Dept. Fish and Game, Juneau, AK.

Joyce, T.L., and D.G. Evans. 2001. Using thermally marked otoliths to aid the management of Prince William Sound pink salmon. NPAFC Technical Report 3: 35-36.

Urawa, S., P.T. Hagen, D. Meerburg, A. Rogatnykh, and E. Volk. 2001. NPAFC Technical Report 3: 13-15.

Volk, E.C., Schroder, S.L., Grimm, J.J. and Ackley, H.S. 1994. Use of a bar code symbology to produce multiple thermally induced marks. Trans. Am. Fish. Soc. 123:811-816.

Volk, E.C., Schroder, S.L. and Grimm, J.J. 1999. Otolith thermal marking. Fisheries Research 43 205-219.

Volk, E.C., S.L. Schroder, and J.J. Grimm. 2004. Otolith thermal marking. Chapter 22, pp. 435-451 In Stock Identification Methods, Academic Press.

FINDING 12. *These alternative existing technologies cannot, by themselves, replace the CWT system, but they might be used jointly to achieve a similar purpose (e.g., GSI + otolith thermal marking). Although such combination of technologies may be theoretically possible, their combined use could have substantial increased costs and would require a degree of interagency coordination and collaboration that exceeds that which was necessary to develop the CWT system.*

Otolith marking of all hatchery indicator stocks of Chinook and coho salmon is probably logistically and economically feasible and if implemented would provide a potential mechanism to identify age and stock when these fish are caught in fisheries. Practical application to mixed stock fisheries, however, is limited by the number of possible otolith marks that would have to be applied both across the various hatchery stocks and through time to account for multiple age classes of Chinook. It may be possible to overcome this limitation by first splitting stocks into groups that can be easily distinguished by genetic stock identification methods. For example, it is relatively easy to distinguish Oregon fall Chinook from Alaska spring Chinook. As a result, the same otolith mark could be applied to fish in both groups (specific hatchery and brood year). Thus an otolith marking program, if combined with genetic stock identification, could be implemented with many fewer discrete otolith banding variants. However, to implement such a system, a well coordinated otolith marking protocol and reporting system would have to be developed to ensure that duplicate otolith marks were not applied within major genetic lineages over a period of 4 to 5 years. Other types of combined stock identification methods are also probably feasible as replacements for the current coded wire tag program.

While such a combined approach is technically feasible at this time, it would require a greater level of coordination and collaboration among salmon management and research agencies that work in the PSC arena than currently exists. Further, the costs of implementing a combined otolith/genetic approach would exceed costs now associated with the CWT program and might fail to provide some important stock assessment information. Under the CWT program, the contributions of small stocks to mixed stock fisheries can more easily be ascertained by including a larger proportion of these stocks in tag release groups than with larger stocks. However, to achieve the same result with a combined otolith/genetic analysis would require a enormous fishery sampling effort which would be prohibitive to management agencies. Finally, implementation of such a marking and sampling regime would not directly address the key issue of estimating incidental mortalities of fish released in MSFs.

FINDING 13. *Modern GSI methods can be used to estimate the stock composition of the landed catch in a particular time/area fishery. However, the accuracy and precision of data required to estimate stock-age-fishery specific exploitation rates using GSI methods is dependent upon a variety of factors. For example, microsatellite DNA-based GSI technology is not yet capable of generating consistent, replicable estimates due to the lack of a coast-wide genetic baseline, the history of stock transfers within and among watersheds, and differences in methodologies and mixture separation algorithms.*

FINDING 14. *Although GSI methods can provide estimates of stock composition in catches or spawning escapements, they cannot provide (with the exception of FPG (see Finding 18) information on age or brood year contribution from a particular stock. This information is, of course, required for estimation of age-fishery-specific exploitation rates. Theoretically, GSI data could be augmented by aging data, e.g., data based on scales, to rectify this difficulty. Unfortunately, we do not believe that reliable ages of chinook salmon or coho salmon captured in mixed stock ocean fisheries can be obtained consistently by reading of scales. Based on a review of published and unpublished studies, it seems clear that aging errors can be substantial and that these errors are largely attributable to scale resorption (in freshwater) or ambiguities in identification of freshwater annuli (juvenile life history).*

Although GSI methods would provide a means to estimate stock composition in ocean fishery landings or in pre-fishery test samples of legal- or sublegal-sized fish, such data could not be used by themselves to generate a direct estimate of age- and fishery-specific availability or landings as is commonly required for fishery management. The Expert Panel was therefore keen to learn whether or not scales could be used to reliably estimate ages of coho and chinook salmon in ocean fishery landings or in pre-fishery samples. Scales could be taken rapidly and non-destructively from landed catch or from pre-fishery samples and would therefore be an ideal structure for aging if they were suitably accurate.

Although the relevance of the subject of scale aging of salmon was of clear importance, no presentation on this topic was made at the June 2004 workshop. At our 14-15 January 2005 full Panel meeting in Vancouver, however, Rick McNicol, DFO, presented a detailed presentation on scale aging errors for chinook and Leon Shaul, ADFG, via conference call, discussed his findings concerning aging errors of coho salmon.

McNicol summarized results of several studies of aging chinook from scales (Bilton 1985, Yole 1989, Flain and Glova 1988, Chilton and Bilton 1968, Godfrey et al. 1968, Kiefer et al. 2001) and, despite widespread evidence of substantial aging errors in several studies, concluded that total ages of ocean-caught hatchery-origin chinook could be reliably determined by highly skilled scale readers. He expressed concerns regarding scale resorption in fish caught in freshwater, however, and also noted that there was a strong need for age validation work on wild stocks of chinook that may have more complicated juvenile life histories. In many chinook stocks, fish may spend considerable time in estuaries prior to out migration; false annuli and/or rapid changes in scale growth rates may reflect this estuary transition and complicate interpretation of scale patterns. McNicol also emphasized, however, that high accuracy of age determinations could only be achieved by highly experienced scale readers. Individuals with

limited scale reading experience were much less accurate in their determinations of total ages, largely because of difficulties in interpretation of freshwater life history (typically, stream - 1+ smolt – versus ocean – 0+ smolt).

Shaul presented very disturbing scale aging data for coho salmon from Southeast Alaska. Again, errors of total age (and hence brood year) resulted from difficulties in determination of freshwater life history. Coho salmon from Southeast Alaska may spend from one to three years in freshwater prior to out migration.

Together, McNicol's review of published and unpublished studies on aging chinook salmon and Shaul's description of experiences in aging coho salmon from Southeast Alaska cause us to believe that scale aging could not be expected to produce accurate determinations of total age for either species if it were to be applied on a coast-wide basis as the primary method to convert GSI assignments of stock type to stock type and brood year. Among other things, it would be impossible, in practice, to ensure that scale readers would consistently be drawn from the small group of "highly experienced" scale readers.

Citations

Bilton, H.T. 1985. unpublished MS. A test on the accuracy of ageing of chinook salmon of known age from their scales. Submitted to the Internat. N. Pac. Fish. Comm.

Chilton, D.E. and H.T. Bilton. 1986. New method for ageing chinook salmon using dorsal rays, and evidence of its validity. Can. J. Fish. Aquat. Sci. 1588-1594.

Flain, M., and G.J. Glova. 1988. A test of the reliability of otolith and scale readings of chinook salmon. New Zealand J. Mar. Fresh. Res. 22: 497-500.

Godfrey, H., D.D. Worlund, and H.T. Bilton. 1968. Tests on accuracy of ageing chinook salmon from their scales. J. Fish. Res. Board Can. 25: 1971-1982.

Kiefer, R.B., J. Johnson, P. Bunn, abd D. Anderson. 2001. Part 1 – Monitoring age composition of wild adult spring and summer chinook salmon returning to the Snake river basin. IDFG report # 01-41.

Yole, F.Y.E. (1989). Criteria for identifying freshwater age from scales of chinook salmon (*Oncorhynchus tshawytscha*) captured in mixed-stock fisheries of British Columbia. Can Tech. Rep. Fish. Aquat. Sci. No. 1628.

FINDING 15 *Large sample sizes will be necessary to use GSI methods to generate reliable estimates of fishery contributions for small (often natural) stocks, and results will be sensitive to small assignment errors for large stocks and ages.*

The principal focus of the PSC's management regimes is regulation of fishery-specific impacts on individual stocks of Chinook and coho salmon. Currently, monitoring and assessment of impacts on natural stocks are inferred from cohort analyses performed on recoveries of release groups of indicator stocks containing unique CWTs. These recoveries provide unequivocal information regarding the origin and age of individual fish, as well as information on location and timing of tag recovery.

In general, GSI provides estimates of stock composition, but such estimates are not required for current PSC chinook and coho management. To provide the data necessary to implement PSC chinook and coho regimes, stock composition estimates would have to be converted into data suitable for cohort analysis, i.e., estimates of contributions for individual release groups. In theory, if individual fish can be accurately associated with specific release groups throughout the migratory range of the stocks using GSI-based stock composition estimates in combination with other information (e.g., age of individual fish), the data required to perform cohort analyses can be obtained simply by multiplying percentage compositions by the catch sample size. In practice, however, the ability of GSI methods to associate individual fish to specific populations can be difficult because many populations of hatchery and natural stocks share a common genetic origin and accurate aging is generally problematic (see *Finding 14*). Another important issue is that errors in assignment to population of origin can be introduced into the analyses when using GSI. When errors are made in the assignment of individual fish to stock they can have a large effect on bias of fishery impact estimates and also affect estimates for other stocks. (See Appendix H for illustrative examples.)

The capacity of a GSI system to accurately estimate the contribution of an individual stock improves as the proportion of the stock in the fishery increases. That is, for a given sample size, the contribution of major stocks can be estimated better than the contribution of minor stocks.

With CWTs, the efficiency of sampling is improved because of the capacity to rely upon a visual cue to identify tagged fish (e.g., adipose fin clip) and a proportional increase in the tagging rate means that smaller stocks can be "enriched" for tags. The use of an external identifier and similar release group sizes allows contributions of large and small stocks to be estimated from CWT recovery data with similar error. In contrast, GSI, combined with an external mark to identify fish to be sampled would produce disproportionately large errors for small stocks, as they will be sampled infrequently in the fishery relative to larger stocks. However, the number of "tags" for a particular stock with a GSI system would probably exceed that likely to be available under a CWT-based system.

If the only objective of the fishery sampling is to determine the contribution of the predominant stocks in the fishery, than the number of fish that must be sampled and processed with a GSI method can be greatly reduced compared to the CWT system. However, when the purpose of the sampling is to detect the impact of the fishery on all contributing stocks, particularly those which comprise a relatively small proportion of the fished population and when it is necessary to

estimate specific stock-age fishery impacts, the amount of sampling for GSI methods to estimate impacts on small stocks that have received CWTs is likely to be far higher than under the CWT system. Relying upon information from small GSI samples as the means to reconstruct cohorts would substantially increase the uncertainty in the management system. Leaving aside issues of correct stock and age determination, unless very large samples of tissues are processed, the error in estimates of data required for cohort reconstruction and analysis is likely to be very large. Considering the uncertainty regarding the estimates of stock-age-specific impacts that are likely to result from combining estimates from many strata, the likelihood of being able to accurately reconstruct a cohort using only GSI data is extremely small.

FINDING 16. *If sampling programs were sufficiently well designed, GSI methods could be employed to gather information on the incidence of particular stocks and identify opportunities for time-area management measures to reduce fishery mortalities of natural stocks of concern. However, stock-specific management approaches in the aggregate abundance based management fisheries (AABM) would need to be carefully evaluated and agreed upon by the PSC to ensure that the harvest rates on other stocks do not exceed the target levels appropriate for the AABM abundance index as established under the 1999 PST agreement.*

PSC Fishery Regimes

The 1999 PSC chinook agreement establishes two general types of fishery regimes: (1) Aggregate Abundance Based Management (AABM); and (2) Individual Stock-Based Management (ISBM).

AABM Regimes

Major mixed stock fisheries off Southeast Alaska (all gear), Northern British Columbia (troll and sport), and West Coast Vancouver Island (WCVI troll and sport) operate under AABM regimes. These regimes are intended to: (a) adjust fishery harvest rates in response to estimated abundance of all stocks combined; and (b) reduce uncertainty for fishery management planning to meet stock-specific conservation objectives.

For AABM fisheries, abundance is indexed to stock-age population sizes through the use of an index estimated by the Chinook Technical Committee's Model. The index is derived by applying annual fishery exploitation rates for the troll component of the AABM fishery complex during a specified historical base period to two estimates of stock-age specific abundance: (a) forecasts for the coming season; and (b) observed levels during the model base period. The abundance index thus reflects the relative abundance for the coming year to that observed during the model base period when fishing patterns are consistent with those observed under the base period. The allowable fishery impact (initially landed catch, eventually changing to total mortality) is derived from a negotiated relationship between the abundance index and the allowable fishery harvest rate.

In recent years, fishing patterns in Canadian AABM fisheries have been altered in-season in response to information obtained from GSI samples in an attempt to constrain mortalities of stocks of conservation concern to Canada. Times and areas of fishing and important regulatory measures such as size limits have changed drastically from those in place during the base period. For example, during the base period, the predominant impacts from WCVI fisheries occurred in the entire area during the summer months. Recently, fishery managers have focused on reducing impacts to chinook from WCVI and southern Strait of Georgia rivers, and interior Fraser coho. Now; the chinook fishery predominantly operates offshore (to minimize impacts on WCVI and Strait of Georgia

chinook)[11] during the October-June time period (to minimize impacts on interior Fraser coho) under reduced minimum size limit restrictions (to provide targeted marketing opportunities and reflect the smaller size of fish available during the winter-spring time frame).

While in-season management actions based on well-designed GSI methods could be usefully employed to address conservation concerns for some stocks, such measures could be fundamentally incompatible with the objectives of the 1999 PSC chinook agreement. Unless sample sizes for GSI analysis are very large, the methods are unlikely to provide useful estimates of contributions of stocks that comprise a small proportion of the catch. These smaller stocks are often of greatest conservation concern.

Management actions in AABM fisheries which are taken in-season to reduce impacts on selected stocks raises three major concerns. First, the abundance index would no longer be appropriate to establish the allowable level of fishery impacts. For example, in the WCVI troll fishery, the stock-age specific fishery exploitation rates during the base period were estimated from coded wire tags that were predominantly collected during the summer time period that is no longer being fished. In addition, stocks that are intentionally being avoided by in-season management historically comprised a significant portion of the WCVI harvest (4%-8%) during the base period and thus affect the values of the abundance index. The technical basis for deriving the abundance index, which establishes allowable AABM fishery impacts with the objective of constraining fishery harvest rates, is undermined. Second, since fishing patterns can vary markedly from year to year, a primary purpose of the AABM regimes, to reduce uncertainty for stock-specific management planning, would be rendered meaningless. Further, instability in fishing patterns diminishes the capacity to incorporate information from catch sampling during more recent years (compared to the 1979-1982 base period) into usable estimates of exploitation rates if AABM regimes are to continue in effect in the future. Third, maintaining the same level of impact (in terms of allowable catch or mortality) while avoiding selected stocks, increases impacts on other stocks. This raises issues of "fairness" of the negotiated fishing agreements by undermining the relationship between aggregate abundance and the general objective of constraining fishery impacts on the total stock complex being exploited by the AABM fishery.

ISBM Regimes

The 1999 PSC chinook agreement requires that fisheries that are not conducted under AABM regimes are managed to constrain total mortality, adult-equivalent harvest rates on individual natural stocks that do not meet agreed to spawning escapement goals. The 1999 Agreement calls for reductions in a harvest rate index in relation to levels observed during a specified base period. The ISBM obligation applies to the aggregate impact of all non-AABM fisheries within the individual jurisdictions of Canada and the United States on individual stocks. ISBM regimes commonly operate under domestic

[11] In the latest available calibration of the CTC Model (#0506), WCVI and lower Strait of Georgia stocks are estimated to comprise from 4% to 8% of the WCVI troll catch during the 1979-1982 base period.

management agreements that are designed to achieve spawning escapement and harvest allocation objectives throughout the migratory range of the stocks.

In certain circumstances (e.g., terminal area fishery management), in-season GSI information could be usefully employed in ISBM fisheries to help reduce or constrain fishery impacts on selected stocks that are not projected to meet established escapement goals. However, the difficulty of planning and conducting ISBM fisheries to meet management objectives and constraints can also be profoundly affected by substantial year-to-year variations in AABM fishing patterns that respond to in-season information. ISBM fisheries bear the brunt of uncertainty associated with the conduct of AABM fisheries since they frequently operate on maturing fish. Since spawning escapement levels are ultimately determined by the cumulative impact of AABM and ISBM fisheries, an additional burden can be placed on ISBM fishery managers to compensate for increased uncertainty in the conduct of AABM fisheries. This increased uncertainty was not anticipated when the 1999 Agreement was reached and undoubtedly will affect perceptions, which in turn are likely to increase the difficulty of negotiating agreements on future fishing regimes. Greater uncertainty in AABM fishery impacts can disrupt the capacity to successfully negotiate and prosecute management agreements that affect conservation and allocation objectives.

Further, if the ultimate result of instability in fishing patterns is increased uncertainty and the failure to attain spawning escapement goals, paragraph 9 of the 1999 PSC chinook agreement contains provisions for adjusting both AABM and ISBM fisheries with the potential end result of an almost endless reshaping of both AABM and ISBM fisheries.

FINDING 17. *Over the past 20 years, first allozymes and more recently microsatellite markers have become the dominant molecular tools for use in GSI. However, the Panel believes that microsatellites will be replaced by SNPs in the next several years as the tool of choice for salmon population genetic applications, as has already occurred in human genetics. The first step in the transition in marker type is the identification of appropriate SNP markers, a process that is already underway for Chinook salmon data with the multi-agency project funded this year by the Chinook Technical Committee. SNP marker development and databases are also well underway for sockeye and chum salmon. Factors driving the replacement currently include the ease of data standardization and high throughput. Cost-effectiveness will become an important factor as more SNPs are developed and multiplex processes drive the cost of analysis down.*

Genetic "baseline" databases have proliferated within the Pacific Salmon Treaty area and throughout the Pacific Rim (see Appendix D). Many of these have been based on microsatellite markers used in single laboratories and produce data that cannot be easily combined or compared with that from other genetic databases. There is also substantial redundancy in the geographic (stock) coverage of these databases. The proliferation of such un-standardized genetic databases represents an inefficient use of valuable resource management funds, as the stock proportion estimates derived from them can not be independently verified and the variation in stock coverage can be extreme, with some stocks represented in more than one database, and others in none.

The development of a standardized genetic database for Chinook salmon has been funded through the $1.1M "Genetic Analysis of Pacific Salmonids: Development of a Standardized Microsatellite DNA Database for Stock Identification of Chinook Salmon" project. This project includes provisions for archiving tissues and/or DNA included in the database to allow for the expansion with new genetic markers as they are developed and without the expense of additional sampling and tissue exchange.

Standardized "baseline" genetic databases have the following characteristics:

1. Are based on the same genetic markers,
2. Produce data that is readily repeatable, and thus results that are independently verifiable in any laboratory
3. Produce data generated in one laboratory that can be easily combined with data generated in another,
4. Are freely available to all scientists, managing agencies or other interested parties for review and utilization,
5. Encompass the range of the species at a geographic scale appropriate to the analytical methods employed and, minimally, to address management objectives of the PSC, but preferably for the entire Pacific Rim.

Some marker types are more easily standardized than others. SNPs are perhaps optimal in this sense, as the alleles represent the absolute character state (the 4 underlying nucleotides that are the building blocks of all DNA), thus eliminating the difficulties and costs associated with standardization of markers such as microsatellites, where alleles represent relative lengths of repetitve tracts of DNA. Development of SNP markers for

salmon over the past year has been rapid and some agencies are already making limited use of these markers for genetic stock identification. In addition to the ease of standardization, this class of DNA marker offers other advantages, including high throughput, low error rates, and potentially greatly reduced cost, relative to microsatellites or allozymes, due to multiplexing and automation capabilities. Costs of SNP genotype determination for humans are already far below that of microsatellites and a small fraction of current costs for microsatellite genotype determination in salmonids.

For these reasons, we believe that standardized SNP baseline databases should and will soon replace the plethora of microsatellite baseline databases that have been employed by individual agencies for genetic stock identification over the past several years.

FINDING 18. *A novel genetic method, termed full parental genotyping (FPG), has been presented as an alternative to coded wire tagging. The method uses genetic typing of hatchery brood stock to "tag" all hatchery production. The tags are recovered through parentage analysis of samples collected in fisheries and in escapement. Because of the need for a low laboratory error rate, FPG would rely on SNP markers. FPG would provide the equivalent of CWT recovery data, and could be easily integrated with a GSI system to provide stock of origin for all fish and stock + cohort for all fish from FPG hatcheries. However, further evaluation of the relative costs of FPG, GSI and CWT systems is needed. Moreover, an empirical demonstration is needed to validate theoretical results that indicate broad feasibility*

A Description of Full Parental Genotyping[1]

SUMMARY

This report describes how full parental genotyping (FPG) could be implemented as an alternative, or complement, to coded wire tagging (CWT) of hatchery salmon in the Northeast Pacific. The FPG method works by genotyping the broodstock at hatcheries and including their genotypes in a database (the *parent database*) from salmon spawned each year. The genotypes of fish sampled in fisheries, at hatcheries, or on natural spawning grounds can be compared to those in the parent database. With a sufficient, and surprisingly modest, number of genetic markers, the exact parents of any sampled fish can be identified, provided the parents' genotypes are in the parent database. Knowledge of the parent pair producing a recovered fish provides managers and biologists with the hatchery of origin *and* the cohort of the recovered fish precisely the information provided by a coded wire tag recovery and required for implementing current CWT-based cohort reconstruction models for fisheries management. Thus, the FPG method can provide managers with all of the same information as the CWT program. In addition, an FPG program would have considerable collateral benefits. Most notably:

- The per-fish tagging cost of FPG would be considerably lower than that of the CWT program, and a *much* higher proportion of adipose-clipped production could be tagged; All juvenile production from FPG hatcheries would be tagged.
- The higher proportion of tagged fish may eliminate the need for a secondary, electronic tag detection method in sampling of harvest or in escapement.
- Heads of recovered fish need not be removed; only a small piece of fin must be collected and sent for genetic analysis.
- The parent database could easily be integrated into a genetic stock identification (GSI) database that shares molecular markers, allowing both adipose-clipped, but non-FPG, and naturally spawned fish to be identified to stock, and sometimes cohort, of origin. Such an integrated FPG and GSI system would provide information about stock of origin for every sampled fish, marked or unmarked.

The most important potential limitations of the FPG method are *i*) it is most cost-effective for cohort-based management only when a large proportion of adipose-clipped fish are offspring of parents in the parent database, *ii*) it will be difficult to "tag" natural spawning fish via FPG, because it is not easy to capture the majority of natural-spawning salmon and include them in the parent database (however, GSI analysis could yield stock of origin and, in some cases, the cohort of natural spawning fish), and *iii*) since the proportion of FPG-tagged fish from all hatcheries would be high, it is not possible to enrich the representation of fish from "weak" stocks amongst all tagged fish. However, it is important to note that the absolute number of tagged fish from "weak" stocks will be greater with FPG, with essentially all fish from such stocks tagged.

[1]Eric C. Anderson and John Carlos Garza, Southwest Fisheries Science Center, National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060, 27 April 2005

1 INTRODUCTION

Since the late 1960's coded wire tags (CWTs) have been used to track salmon released from hatcheries and, occasionally, fish produced on natural spawning grounds. CWTs are mechanically implanted in the heads of juvenile fish and each tag contains a code that is unique to each release cohort and location (hatchery). Tagged fish receive an externally-visible adipose fin clip which aids in the recovery effort of the tags. Until 1996, the only fish with an adipose fin clip were those that also carried a CWT. Since that time, federal and state laws and regulations have been enacted that require the mass marking (with adipose fin clips) of most hatchery production. This would enable the administration of mark-selective fisheries, in which only hatchery fish bearing the adipose fin clip are retained, and unmarked (presumably wild) fish, if caught, are released. Such mass-marking presents a serious challenge to the use of CWTs for fisheries management, because finding a CWT amongst the fin clipped fish becomes a needle-in-a-haystack problem and a great many fin clipped fish may have to be screened to find one with a CWT.

The Pacific Salmon Commission has convened a panel of experts to explore ways of updating, complementing, or replacing the CWT system to deal with the problem of mass-marked hatchery production and consequent mark-selective fisheries. Prior to the formation of this panel, the primary proposal for amending the CWT system has been to implement a program of electronic survey, outfitting field sampling crews in fisheries and hatcheries with metal detectors to screen a large number of (mostly adipose-clipped) fish to find the ones carrying CWTs. Such a program would incur very high initial capital costs and substantial annual labor costs. Another strategy is to tag a higher proportion (perhaps all) of the fish receiving adipose fin clips, so that the hatchery and cohort of any adipose-clipped fish that was recovered could be identified. This would eliminate the need for electronic detection. However, it would be cost prohibitive, because of the enormous number of hatchery produced juveniles and the cost of tagging fish with CWTs.

We propose an alternative to tagging with CWTs called "full parental genotyping" (FPG). It uses genetic analysis, but, unlike better-known genetic stock identification (GSI) methods, it provides both stock of origin and the cohort for recovered fish. FPG relies on the simple principle that if you identify where and when the parents of a recovered fish spawned, you will obtain the location and cohort of origin for that fish. Identifying the exact parents of recovered fish is done by comparing the genotype of the recovered fish to the genotypes of possible parents and identifying the exact parent pair through traditional parentage analysis. Because FPG is most easily implemented in a hatchery, which is precisely where both current CWT programs and mass marking is occuring, it is feasible with FPG to tag most hatchery production and therefore most mass-marked fish. Our analyses have shown that FPG can be implemented at a cost that would be competitive with the current CWT program and, possibly, less than that of a CWT program with electronic detection. We describe the results of these analyses and discuss the advantages and limitations of FPG.

The following section briefly discusses parentage analysis, single nucleotide polymorphisms, and the number of genetic loci that would be required to implement FPG with low error rates. Section 3 discusses how and why the cost of tagging individuals via FPG is less than that of coded wire tagging, and Section 4 discusses the cost of tag recovery using FPG relative to that of CWT. Section 5 discusses how the genotyping done for FPG could be used in a GSI context, as well as an FPG context. Section 6 considers what additional steps should be taken to make FPG as useful

as possible in the context of recovering fish from weak stocks, and Section 7 discusses how FPG would work within the context of a double index tagging approach. Finally, Section 8 describes the additional, useful information that would come from the FPG approach and Section 9 discusses what steps have been taken toward developing the molecular tools required for FPG.

2 PARENTAGE ANALYSIS, SNP MARKERS, AND NUMBER OF LOCI

The application of FPG first requires determination of the genotypes for the parents (broodstock) of all fish from a particular hatchery cohort. These genotypes are recorded in a *parent database*. Later, when a fish is sampled in a fishery or in the escapement, its genotype is compared with every parent pair in the parent database from spawning years that could possibly have given rise to that fish, to determine its exact parents. This assignment of individuals to parents is an example of pedigree reconstruction. Parentage analysis and other methods of pedigree reconstruction with molecular genetic markers have been used routinely in human populations and natural populations of plants and animals since the 1970's. Most of the statistical methodology for parentage analysis was pioneered in a classic paper in the 1970s (THOMPSON 1976), and was later expanded upon to address the nuances of pedigree reconstruction in natural populations (MEAGHER and THOMPSON 1986; THOMPSON and MEAGHER 1987).

As applied to FPG, parentage analysis using a likelihood approach is relatively straightforward. Briefly, imagine that we wish to test whether an ordered trio of individuals (y, m, f) represents a youth (y) and its mother (m) and father (f). Given the frequencies of different alleles at different genetic loci in the population, it is possible to compute the probability $L(Q)$ of the genotypes of the trio under the assumption that they are a youth-mother-father family. It is also possible to compute the probability $L(U)$ of the trio under the assumption that they are, in fact, all unrelated individuals (or any other combination of related and unrelated individuals). The test statistic $\Lambda = L(Q)/L(U)$ is useful for identifying trios that are true youth-mother-father families. For such "correct" trios, Λ will be large, and a critical value Λ_c can be used to classify trios into "correct" and incorrect categories. In other words, if Λ for a certain trio was greater than Λ_c you would conclude that the parents of y were indeed m and f. If however, Λ for that trio was less than Λ_c, you would conclude that m and f were not the parents of y. By approximating the distribution of Λ for youth-mother-father trios and for unrelated trios, it is possible to compute the probability that an unrelated trio will have a Λ greater than Λ_c and also the probability that a "correct" trio will have a Λ less than Λ_c. These values give the per-trio probability, α, of false-positives (declaring m and f the parents of y when they are not) and the per-correct-trio probability, β, of false negatives (declaring m and f are not the parents of y when, in fact, they are), which can be used to determine how many genetic marker loci would be needed to perform FPG accurately.

In parentage analysis with genetic markers, a low laboratory error rate is crucial, as such errors can result in mismatches between true parents and offspring, which can incorrectly decrease Λ. We propose using a type of genetic marker locus for FPG called a single nucleotide polymorphism (SNP), which has a low laboratory error rate. Another confounding factor for many commonly used genetic markers, particularly microsatellites, is that mutations arising during meiosis appear as mismatches, which can, again, incorrectly decrease Λ. The per-locus mutation rate of SNP

markers is several orders of magnitude lower than that of microsatellites, and fewer mutations are thus expected to appear in individuals tagged with FPG using SNPs than using microsatellites, which currently dominate pedigree reconstruction efforts.

SNPs typically have only two alleles, and these alleles represent the absolute nucleotide state of the marker (as opposed to relative size or gel mobility, as with microsatellites and allozymes) which makes it possible to determine the genotype of each locus with minimal human interaction. This makes them amenable to high-throughput, automated genotyping, and means it is far easier to standardize markers between different laboratories. The only drawback from an analytical perspective is that SNPs, with only two alleles, have less statistical power per locus for parentage analysis than markers like microsatellites, which may have as many as 100 alleles (*e.g.*, Glaubitz *et al.* 2003). However, the potential efficiency and lower cost of SNP analysis, as well as the substantially lower laboratory error and mutation rates, lead us to believe that they will be a far superior choice for FPG applications.

An important remaining question is how many SNP markers are required to conduct FPG on a coastwide scale. We have undertaken a series of power analyses addressing this question (Anderson and Garza, ms in prep). The most relevant findings of these analyses are: *i*) the false positive rate decreases exponentially with the number of SNP markers used, so it is impossible that the tagging program could ever grow so large that parentage error rates could not be diminished adequately by adding a modest number of additional SNP markers, and *ii*) a set of about 100 SNPs in which the frequency of one of the alleles varied between .2 and .8 is sufficient to have a false negative rate of less than 10% (meaning that 90% of FPG-tagged fish could be assigned to parent pairs) and the false positive rate would be low enough that of all individuals, coastwide, assigned to a parent pair via FPG, you would expect that virtually no individuals would be assigned to an incorrect parent pair.

3 TAGGING OPERATIONS AND COSTS

Tagging fish by FPG involves genotyping their parents at hatcheries. Operationally, it proceeds as follows: at each hatchery producing fish contributing to a fishery, a tissue sample (a small fin clip, for example) is taken from every male and female spawned to create the next generation. Those fin clips are sent to a central laboratory (or one of several laboratories), where the genotypes of the fish are determined. These genotypes then go into the parent database, along with the dates that the fish were spawned and any information about which males had been mated to which females.

Optimally, all matings would be recorded at the hatchery, and the fin clips of all broodstock individuals would be linked to the mating information. This would reduce the number of possible parent pairs that had to be evaluated in the search of the parent database and, therefore, the number of genetic markers necessary to assign parentage at a given total error rate. However, if that requires too much work or attention by hatchery staff, another alternative would be to have hatchery staff prepare a number of ethanol-filled receptacles beforehand and label them with date of spawning. Then during spawning operations, they would place fin clips from all males spawned each *day* into one receptacle and fin clips from females into another. It would be unnecessary for the hatchery staff to record the actual matings or any other information in this scenario. The

tradeoff is that the number of possible parent pairs to be searched in the parent database would increase (the number of possible matings each day is just the number of unordered pairs of male and female samples each day), but the absolute number of false positives incurred by examining the extra parent pairs could be held constant by simply adding approximately 8 additional genetic markers to the analysis. With this alternative, there is some possibility that multiple fin clips from a single male might be taken and deposited in the receptacles, but this would easily be recognized from the genotype data, and the duplicate samples would be discarded.

The per-offspring tagging cost using FPG is much less than that using CWTs because by genotyping a single parent pair you are "tagging" *all of the offspring that the pair produces*. This eliminates the need to physically implant tags in any juvenile fish (though they will presumably be mass-marked by adipose fin clipping). A rough comparison of tagging costs for chinook salmon using the two methods can be made by making a few assumptions. Imagine that it costs $\$F$ to genotype a single adult salmon at the number of loci required to do FPG. Let each female salmon at the hatchery produce, on average, d juveniles that survive to the age of release, and let the number of males spawned at the hatchery be equal to the number of females. Under these assumptions it costs, on average, $\$2F$ to tag d juveniles by FPG, or, the per-juvenile tagging cost of FPG is about $\$2F/d$. By comparison, if it costs $\$C$ to tag 1,000 juveniles with CWT, then the per-offspring CWT tagging cost is $\$C/1000$. Now, suppose that we wish to determine what the genotyping cost F must be so that we could tag ten times[2] more fish by FPG than by CWT. Then, the cost, per juvenile, of tagging with FPG must be one tenth that of tagging by CWT. This would be the value of F satisfying:

$$\frac{2F}{d} = \frac{1}{10} \times \frac{C}{1000} \quad \Rightarrow \quad F = \frac{dC}{20000}$$

Numerical values for C are not well known. Estimates in the literature range from \$70 to \$130 per 1,000 fish for coded wire tagging. Let's use $C = \$100$. Chinook salmon are highly fecund and egg to smolt survival is typically fairly high in hatcheries, so we will use $d = 4000$. Using these figures, we conclude that if it is possible to genotype fish for \$20, then *ten times* as many fish can be tagged with FPG as with CWT for the same price.

Currently the cost of consumables used in genotyping a SNP locus with the Applied Biosystems Inc. SNP-plex genotyping system (one of several instrument/reagent platforms available) is approximately \$0.06 per SNP. For a 100 SNP panel, the consumables cost is thus \$6. For microsatellites, a reasonable estimate of the additional genotyping costs (labor, *etc.*) is twice the consumables cost (Paul Moran, pers. comm.). This is likely an overestimate for SNPs which are less labor intensive, but, nonetheless, that gives us \$18 as the cost of genotyping a fish with a 100 SNP panel. If we add the reasonable figure of \$2 per fish for transporting and extracting the DNA, we have \$20 per fish as a cost that could be reasonably achieved today for a 100 SNP panel. In addition, this cost is several times the current cost for SNP genotyping in humans and model organisms, so the cost of SNP genotyping in salmon is likely to fall substantially in the future as it becomes more widespread and more capital (equipment) investment is made by managing agencies.

[2]We show this calculation for a factor of ten, because, though it seems accurate numbers are difficult to come by, we have been told that if mass marking of hatchery fish occurs, then roughly only 10% of adipose-clipped fish will carry CWTs. Therefore, if you can tag 10 times more fish, then you can tag most if not all of the mass-marked production. Hence, we are presenting the cost of genotyping required in order to be able to tag all of the mass-marked production by FPG for the cost of coded wire tagging only 10% of it. If the proportion of CWT'ed fish amongst all mass marked fish would be different, then it is obvious how the calculation should be amended.

4 RECOVERY OPERATIONS AND COSTS

Recovery of FPG tagged fish in harvest, in escapement, or as strays to spawning grounds will proceed much as it does today for adipose fin-clipped CWT fish. However, instead of sending heads to a head lab, fin clips will be sent to a genetics lab for DNA extraction and genotype determination. A potential major benefit of an FPG program is that it would not be necessary to electronically survey mass-marked fish because each fish missing an adipose fin, and from a hatchery in which the broodstock had been genotyped, would contain a tag that provides information about origin and cohort. Of course, the magnitude of this benefit depends upon the proportion of hatchery production for which broodstock genotypes are included in the parent database.

Recovery of tagged fish at the hatcheries in an FPG program would provide an additional efficiency relative to a CWT program. This is because either all or a large proportion of the fish that are genotyped as part of the effort to tag fish, can also be used as tag recoveries from the escapement. Because of this, the hatchery staff should select fish for spawning as a random sample from the fish arriving at the hatchery during any time period. This would ensure that the FPG tag recoveries that are gained in the process of genotyping the fish spawned at the hatchery are a random sample of the tags coming back into the hatchery, as well as preventing a possible mechanism for hatchery selection. Depending on the proportion of fish returning to hatcheries that are used as broodstock and the amount of escapement sampling necessary, it might also be important to sample (*i.e.*, genotype) some proportion of returning adults that are not spawned.

Although the cost of recovering and decoding a CWT is not well known and likely quite variable, the cost of genotyping a fish (to recover its FPG tag) will likely exceed the cost of decoding a CWT from that fish. Quoted costs per fish of decoding a CWT vary from \$3-\$5 per fish (Hammer and Blankenship 2001) to \$11 per fish (Bowhay 2004), whereas the current cost of providing a 100 SNP genotype is approximately \$20, although it should be much lower within the next decade. Moreover, the CWT costs cited above are without electronic sampling, which, when taken into account, may make the current cost of tag recovery for the two methods roughly similar. When the overall costs of tagging (lower with FPG) and tag recovery (likely higher with FPG) are taken into account, an FPG system should compare favorably with a CWT system, particularly if some value is placed on the collateral information gained by FPG (see Section 8).

5 INTEGRATION WITH GENETIC STOCK ID

One of the primary advantages of FPG is that it is easily integrated into a management regime that uses both FPG, for participating hatcheries, and genetic stock identification (GSI), for naturally spawning and non-FPG hatchery populations. A subset of the genetic markers used in FPG can be used for GSI in an initial genetic assay that assigns fish to stock of origin, with each of the FPG hatcheries representing a stock. Those fish not assigned to an FPG (indicator) hatchery, will be identified to stock of origin. Those assigned to an FPG hatchery with genotyped broodstock would then be subject to genotyping of additional markers to determine specific parents and, therefore, cohort. Such a system could accomodate any proportion of marked/unmarked fish, thus allowing the same set of genetic markers to be used in a sequential genotyping effort that provides stock of

origin for all fish, marked or unmarked, as well as cohort of origin for fish from FPG hatcheries.

Moreover, it is frequently possible to accurately assign fish to a particular stream/population of origin *and* cohort/broodyear with a simple GSI and data from 15-20 microsats and 50-100 samples per cohort. There is apparently substantial variation in allele frequencies from year to year in many salmonid populations, which seems to be higher in smaller (weaker) stocks/populations. It may, therefore, be possible to type a modest number smolts or carcasses from "weak stocks" with no FPG hatcheries each year and use those in a relatively large GSI effort on both marked and unmarked fish to provide the tag recoveries for weak stock, cohort-based management.

It will cost several million dollars each year to implement such fishery sampling along side an FPG system for hatcheries, but it will allow identification of *all* fish from any weak stock that you can sample with a trap or carcass survey. It will likely provide small recoveries for many/most stocks, but there will be *some* recoveries for many more stocks than with the current system. Such a combined GSI/FPG system can also easily be scaled (*i.e.*, number of fishery samples) to the level of precision needed/tolerable to management agencies. Such a system would also provide better management for weak stocks not associated with indicator hatcheries, which, by design, are completely missed by the current management regime.

At many hatcheries, a modest fraction of all returning adults are used as broodstock with the additional fish turned back into the river, either above or below the hatchery. When these fish are handled, a small tissue sample can be taken and a genotype obtained, thereby providing tags for all of that individual fish's offspring. This will allow direct evaluation of the assumption of current management strategies that the tagged hatchery release groups are representative of associated naturally-spawning stocks.

6 WEAK STOCKS

The estimation of fishery- and cohort-specific impacts on rare, or weak, salmon stocks is difficult using any tagging program, because their relative scarcity makes substantial numbers of tag recoveries unlikely. Traditionally, the CWT program has scaled the tagging rate of such weak stocks, such that a greater proportion are tagged and the probability of recovering a tag from a weak stock is similar to that of more abundant stocks. While FPG does not provide a specific mechanism to enhance the tagging rate of such weak stocks, it offers the advantage that all fish produced at hatcheries representing weak stocks would carry a tag. The estimation of parameters for fishery management would then require a larger fishery sample with FPG than with a CWT + electronic detection program, but the cost of typing a larger fishery sample would be offset by the savings from eliminating electronic detection. It might also be possible to use an additional external tag on only the weak stocks, so that they are readily identifiable in a mixed fishery context. Moreover, the use of an integrated FPG/genetic stock identification system (see previous section), would provide information on fishery impacts on weak stocks not represented by FPG hatcheries.

7 ESTIMATING INCIDENTAL MORTALITY

In a mark-selective fishery (MSF) only those fish bearing a mark (*e.g.*, an adipose fin clip) are retained. Unmarked fish are released in the hope that they will survive either to be caught in a non-mark-selective fishery, or to spawn. MSFs have the potential to reduce fishery impacts on small, weak stocks (which would not be marked) while still allowing exploitation of fish from large hatchery stocks producing marked fish. However, it is challenging to assess how well MSFs achieve their goal, because it is difficult to estimate the additional mortality that unmarked fish may experience due to being caught and released in an MSF. This additional mortality is termed "incidental mortality."

The method of *double index tagging* (DIT) offers a way to estimate incidental mortality. In the DIT protocol, fish bearing CWTs are released in two different groups—a marked and an unmarked group. The tags in these fish are then recovered in fisheries and in escapement by electronic detection of CWTs, allowing the estimation of incidental mortality rate of each cohort in different years, given some assumptions about marine survival. At least one of the proposals for the analysis of DIT data (HANKIN 2004) explicitly requires that CWT (or FPG) recoveries be made from marked *and unmarked* fish in the non-mark-selective fisheries. (A directed graph showing the underlying cohort model and assumptions of that proposal appears in Figure 10). A useful feature of CWTs in this context is the fact that they may be electronically detected (albeit at substantial cost) amongst samples of both marked and unmarked fish, facilitating the recovery of CWT in both types of release groups. In contrast, if a fish in an unmarked release group were tagged solely using FPG, there would be no way of verifying its hatchery and cohort, (or even of verifying that it was descended from parents of known genotype) without genotyping the fish. If there are many unmarked fish in the fisheries that do not originate from FPG hatcheries, then it would be impractical to genotype many of them to recover a small number of FPG-tagged fish.

For the above reason, FPG would be most effectively applied in the DIT framework if another, sequestered, preferably externally visible, method of marking the non-adipose-clipped DIT release group was available. For example, if the non-adipose-clipped DIT release groups were clipped on the ventral or pelvic fins, the amount of genotyping necessary to fully implement DIT by FPG would be greatly reduced. Alternatively, both DIT groups could be tagged by FPG, but the marked group fish could have CWTs implanted in them so that they can be detected in electronic surveys of unmarked fish in the fisheries. This scenario could confer cost savings because it would be unnecessary to electronically survey adipose-clipped fish, and the electronic sampling effort for non-adipose-clipped fish could be focused on fisheries most relevant to the DIT study design. Depending on the sizes of two DIT release groups, and the recovery rate, it may be cost effective to implant inexpensive blank wire that can be electronically detected into the unmarked individuals, and recover their stock and cohort via FPG. This will be particularly true as genotyping costs continue to fall.

Another approach to DIT that would be more attractive in an FPG framework would be to develop estimators for incidental mortality that do not rely on independent estimates of the number of unmarked DIT release fish captured in non-mark-selective fisheries. This would eliminate the need for visual or electronic sampling, or genotyping, of unmarked fish recovered in fisheries. Rather, unmarked fish in the escapement to each stock could be genotyped and the relative escapement

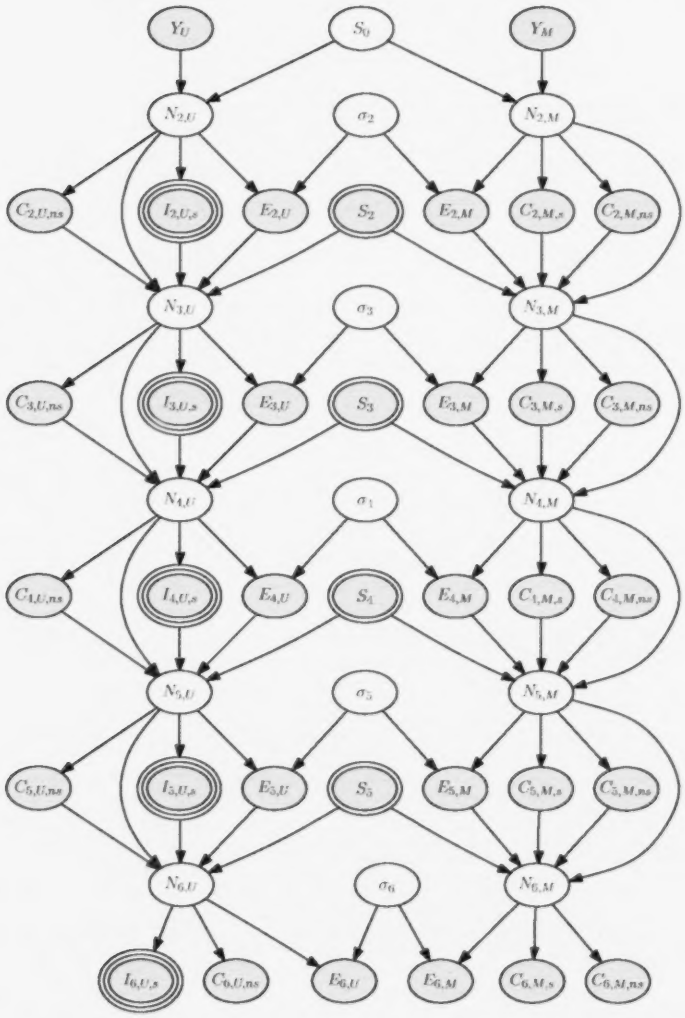


Figure 10. Directed graphical model depicting HANKIN (2004)'s incidental mortality estimation method using double index tagging. Gray nodes with a single periphery are quantities for which estimates are assumed to be available. Gray nodes with two peripheries are variables whose values are assumed to be known. Gray nodes with three peripheries are the incidental mortalities that are to be inferred. The unshaded nodes are unobserved, latent variables/parameters. An M subscript refers to the marked (adipose-clipped) group, and the U subscript refers to the unmarked (non-adipose-clipped) group. Y is the number of fish released. The $N_{a,\cdot}$'s are numbers surviving to age a, and the $E_{a,\cdot}$'s are escapements of each group at age a. The $C_{a,\cdot,ns}$'s are numbers of fish of age a caught in non-mark-selective fisheries and the $C_{a,M,ns}$'s are numbers of marked fish of age a caught in MSFs. The $I_{a,U,s}$'s are the incident mortalities of age a unmarked fish in MSFs. σ_a is the probability that an a-year-old matures. This graph explicitly shows the assumptions that the survival to age 2 is identical for the M and the U groups, and also that the age-specific maturation rates are identical for the two groups.

rates of marked and unmarked groups could be used in a latent variable model to estimate incidental mortality. Such an analytical method would not allow estimation of separate incidental mortality rates associated with each cohort in each particular fishery; however, for many stocks it may be difficult, if not impossible, to obtain precise estimates of fishery- and cohort-specific incidental mortality anyway. ALEXANDERSDOTTIR *et al.* (2004) noted that the per-fishery exploitation rates for most stocks can be estimated only to within a standard error of well over 25% using CWT recoveries. Propagating that much uncertainty through the graph of Figure 10 while trying to estimate the variables at some of its nodes, raises the question of whether it is possible to accurately estimate incidental mortality rates in specific fisheries (HANKIN 2004).

In spite of the difficulty in estimating fisheries-specific incidental mortality rates for many stocks, it is still possible to obtain useful information about the efficacy of MSFs. The most important measure of how well MSFs are working is the overall survival or escapement rate of unmarked fish relative to marked fish. For estimating this quantity in any stock, the FPG approach has the following benefits: 1) it is possible to economically tag most if not all of a hatchery's production using FPG, 2) a portion of the FPG tag recoveries at the hatchery will entail genotyping that will be done anyway (for tagging the next generation) – this provides economical FPG tag recoveries of marked and unmarked DIT groups in the escapement, and 3) the proportion of unmarked fish in the escapement that represent the unmarked DIT group should be much higher than in fisheries, thus alleviating the need for excess genotyping of unmarked fish.

8 ADDITIONAL INFORMATION FROM FPG

As outlined above, the FPG method provides all of the same information as a CWT system and is, thus, a suitable alternative for cohort reconstruction-based fishery management. However, since the FPG method identifies the exact parents of a sampled fish, it actually provides much more information than stock and cohort of origin. Specifically, it allows the evaluation of a host of life history, ecological and quantitative genetic questions, such as the heritability of age at reproduction and disease resistance/susceptability, as well as an evaluation of hatchery domestication, estimation of effective size, and many other biological topics. The ability to collect large samples from fisheries and in escapement will also dramatically increase knowledge of marine distribution patterns and of marine survival.

9 HOW FAR ALONG ARE WE?

One of the main obstacles faced in evaluating and implementing FPG is that few SNPs have been discovered and converted to usable assays in salmon. There are fewer than 50 markers in use for each of the Pacific salmonid species. However, this is changing rapidly, both through the efforts of multiple individual labs and because the Chinook Technical Committee of the PSC has recently awarded a modest amount of money to several genetics labs to develop and evaluate at least an additional 30 SNP markers. The human genetics community developed several million SNP markers over the last decade, once their utility and advantages were clear, and it should be a relatively trivial undertaking for salmon geneticists to develop several hundreds.

An additional area in which human genetics suggests what is possible for SNP genotyping in salmon management is through the dramatic reduction in costs that has been achieved by dedicated genotyping centers. Such centers produce a single SNP genotype for \$0.01–0.02 on a contract basis, although this is after the cost of the capital equipment necessary to outfit the genotyping centers.

References

Alexandersdottir, M., A. Hoffmann, G. Brown, and P. Goodman, 2004 Technical review of the CWT system and its use for chinook and coho salmon management. In *Future of the CWT Program: Challenges and Options. A Workshop June 7–10, 2004.*

Bowhay, C., 2004 Implications of legislative directives to mass mark. In *Future of the CWT Program: Challenges and Options. A Workshop, June 7-10, 2004.*

Glaubitz, J. C., O. E. Rhodes, and J. A. Dewoody, 2003 Prospects for inferring pairwise relationships with single nucleotide polymorphisms. Molecular Ecology **12:** 1039–1047.

Hammer, S. A. and H. L. Blankenship, 2001 Cost comparison of marks, tags, and mark-with-tag combinations used in salmonid research. North American Journal Of Fisheries Management **63:** 171–178.

Hankin, D. G., 2004 Proposed Scheme for Estimation of Total Age-Specific Non-Catch Mortalities to Unmarked Chinook Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries. Technical report, Department of Fisheries, Humboldt State University.

Meagher, T. R. and E. A. Thompson, 1986 The relationship between single parent and parent pair likelihoods in genealogy reconstruction. Theoretical Population Biology **29:** 87–106.

Thompson, E. A., 1976 Inference of genealogical structure. III. The reconstruction of genealogies. Social Science Information sur les Sciences Sociales **15:** 507–526.

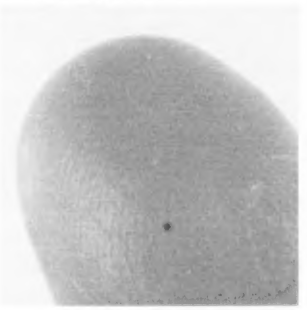
Thompson, E. A. and T. R. Meagher, 1987 Parental and sib likelihoods in genealogy reconstruction. Biometrics **43:** 585–600.

FINDING 19. *A number of existing or emerging electronic technologies could theoretically replace the CWT and may have substantial advantages over the CWT (e.g., tags can be read without killing the fish, unique tags for individual fish allow migration rates and patterns to be directly observed). Examples include at least Passive Induced Transponder (PIT) tags and Radio Frequency Identification (RFID) tags. PIT tags are currently too large to mark all sizes of juvenile chinook salmon released from hatcheries and are expensive relative to CWTs, but future technological improvements may reduce tag size and tag cost.*

Electronic Tags with No External Identifier

Concise Description

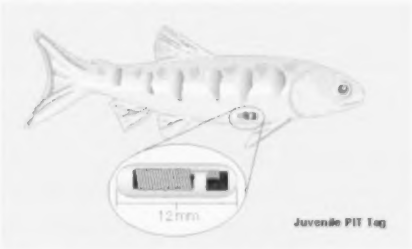
Replace CWTs with tags that can be electronically read while still in fish. Currently, Radio Frequency Identification (RFID) tags are being applied to mark animals and track the movement of items from manufacture to distribution and for use in inventory control. Basically, RFIDs are tiny chips that contain a unique code that can be transmitted to portable radio-wave scanners at a distance of several meters. RFID technology is non-contact, non-line-of-sight, so tags can be read through a variety of substances such as snow, fog, ice, paint, crusted grime, and other visually and environmentally challenging conditions. Because radio waves travel through most non-ferrous materials, they can be embedded in packaging or encased in protective plastic for weatherproofing and durability (water does not generally destroy RFID chips). RFID tags can also be read in hostile environments at remarkable speeds, in most cases responding in less than 100 milliseconds. Due to size and cost considerations, passive RFID tags would likely be employed for animal and fish tagging experiments, that is RFID tags would operate without its own power source, instead obtaining operating power from the reader. Passive tags are much lighter than active tags, less expensive, and offer a virtually unlimited operational lifetime. RFID technology has been applied to track animals (e.g., livestock management) and is presently being applied to fish in the form of a Passive Integrated Transponder (PIT) tag. Each individual tag has a unique code and recovery data can be acquired through electronic readers, without the necessity for lethal sampling.[1] RFIDs could be linked to databases that would provide ready access to a history of the fish, such as its release date and location, brood stocks, and history of any previous encounters.



RFID technology is currently available and is being applied on a limited scale to anadromous fish in the form of Passive Integrated Transponder (PIT) tags. PIT tags are tiny identification chips (about the size of a grain of rice - 11 mm by 2mm) which are injected into animals for permanent, unique identification. With current technology, fish

[1] Liquids tend to absorb the electromagnetic energy required to power the RFID chip and interfere with the accuracy of reading tag codes. Obviously this technical challenge would have to be overcome before RFID technology could be routinely applied in fish tagging studies; research is already underway to find ways to address problems with applying RFID technology to items containing liquids or metals.

must be at least 55mm in length of fish to accommodate PIT tags; consequently, the technology has limited use for tagging fall chinook fingerlings. PIT Tags are RFIDs which are encased in very small glass tubes containing an antenna and an integrated circuit chip. The tag is inserted into the juvenile fish's body cavity and remains inside a fish for its entire lifespan. PIT Tags are read using electronic readers that activate the tag and extract the code. PIT Tag readers can be either portable, work on battery power, or require AC current. Some have the capability to store codes from many animals before they are downloaded to a computer, others simply display the code of the current reading without storage. In the past, reading distances have been very short (less than 30 cm). Current PIT Tag readers are 134.2 kHz (ISO standard) detectors. Compared to earlier technology which employed 400 kHz detectors, 134.2 kHz detectors require less power to energize the tags so the tags can be read at longer distances (~2 meters, important for adult detection). Additionally, the lower power requirement leads to a longer transceiver life cycle, reduced maintenance and higher reliability. Current readers have built-in diagnostic capabilities that can be run on-site or remotely, resulting in considerable savings in troubleshooting time and repairing faulty units. As the tag is read, data about that particular fish is fed into computers for later analysis.



Because RFID tags can be read without killing the host, opportunities arise to gain direct information that has long evaded researchers. Because each fish can carry a unique RFID tag which can be read without lethal sampling, data to estimate natural and release mortality rates, migration patterns and rates, and growth rates can be obtained. However, methods of analysis for such data are still in the formative stages of development.

Major advances in RFID technology are anticipated in miniaturization and tag reading capabilities due to increased investment in efforts to create a global, standardized network for tracking everything that is manufactured, shipped, stocked, and sold, down to the individual item level. Investment in development of RFIDs has already been substantial and is expected to increase greatly due to a recent agreement on global standardization of UHF (which allows greater tags to be read at greater distances and at higher rates) which will allow every reader to read every RFID. As investment and application of the technology increase, the size of RFIDs and readers will become smaller,[2] continued improvements in the speed, accuracy, and range of both RFID tags and readers are expected, and the cost will become cheaper.[3] Information on RFIDs is readily available in technical and trade journals (e.g., http://www.rfidjournal.com/; *http://www.rfidgazette.org/; http://www.aimglobal.org/technologies/rfid/*).

---

[2] In 2003, Hitachi announced it had developed an RFID tag that is 0.3 mm square http://www.rfidjournal.com/article/articleview/337/1/1/ - note: The Hitachi chip operates at 2.45 GHz, a frequency that is currently unsuitable for applications requiring reading through water. In August 2005, Silicon Craft Technology announced that it has developed a 1.14 mm square tag. The smallest readers now available, manufactured by Innovision Research and Technology, are roughly the size of a dime.

[3] Current cost for tags is now US$0.20-$0.50, but RFID tags costing less than US$0.05 have recently been announced.

Hypothetical Framework Electronic Tag Detection:

- Although a variety of marking schemes couple be employed, electronic tagging provides a means to collect data required to estimate stock-age-fishery specific exploitation rates with no external tag identifier by redesigning the tag recovery system. The only external mark required would be for mass marking.

Mass Mark	DIT
Adipose Fin Clip	Electronic Tag + Ad Electronic Tag

- Recovery of electronic tag data could be accomplished efficiently for a very large portion of the catch and escapement. It may be possible to substantially reduce costs and simplify logistics of catch and escapement sampling to recover, read, and report tags compared to the current CWT system while making information on tag observations available more quickly. A brief description of a hypothetical framework system that could be deployed to detect electronic tags follows.
- Accurate information on the location and timing of CWT recoveries by trollers has long been problematic. Trollers commonly fish in different catch areas on a single trip; by having a tag reader located in a plastic cleaning trough coupled with a GPS system, the tag would be automatically be read when the fish are cleaned. Tag information on time and location where fish are recovered could then be recorded and transmitted to a database. It may also be possible to use tag readers to scan fish that are released and estimate release mortality in a mark-recapture experiment – since each fish would have its own unique code, information on migration patterns and multiple hooking events could also be obtained.
- For commercial processors, tag readers could be installed in the processing lines which would eliminate the need for sampling to recover tags.
- For sport fisheries, regulations could be enacted requiring fish to be landed uncleaned (alternatively, innards could be stored in a container that could subsequently scanned to recover tag data).
- For escapement recoveries, in-situ tag readers could be installed in approaches to hatchery weirs, traps or in the streams. PIT Tag readers are already being installed at most main stem dams of the Columbia River.
- For mark-selective fisheries, it may be possible to collect information on encounters of tagged fish released to estimate release mortalities.
- A database for PIT Tag information for the Columbia River system has been designed and is operational.

Concerns addressed:

- Current use of adipose fin clip as a dual indicator for a mass marked fish and the presence of a CWT requires use of electronic tag detection equipment and direct sampling programs. Some agencies are reluctant to incur additional costs and are unwilling to sample for and/or process unmarked DIT fish.
- CWT information can only be obtained when the fish is dead

- Removal of snouts to extract CWTs can affect market value of fish and make processors and fishermen reluctant to participate in tag recovery efforts
- Costs of recovering tag data (sampling catch, removing snouts, decoding in head labs, and reporting.

Advantages:

- Approach would provide at least the same data available through current CWT system for cohort analysis.
- Costs for processing snouts to extract and read CWTs would be eliminated.
- The capacity to efficiently recovery PIT tags from a large proportion of the catch and escapement would reduce the number of tags required for estimation (or reduce uncertainty about recovery estimates if tagging levels are maintained) and alleviate concerns for large sample sizes required to recover tagged fish that comprise a small proportion of the catch.
- Each fish carries a unique code so the method can potentially provide data for estimation of natural and release mortality rates, migration patterns and rates, and growth rates.
- Non-lethal tag recovery provides many opportunities for research projects to provide information that has long evaded researchers, such as estimation of mortality rates and migration patterns. Additionally, non-invasive recording of tag data provides an opportunity to collect data that may become important for management.
- Tags can be recovered without mutilating the fish, preserving market values of the fish and eliminating barriers to processor and fisherman cooperation
- Technology is currently available and being applied. A considerable body of research and knowledge regarding use of PIT Tag technology with salmonids exists (see bibliography; also http://www.pittag.org/web/Workshop_2004/)
- Tag readers at hatcheries could quickly and conveniently provide recovery data on large volumes of fish.
- Tag readers could be installed in small streams or entrances to hatchery traps to recover tag data. This capability would eliminate the need to sample fish at the hatcheries to estimate escapements and could also be used to estimate stray rates (some research on small stream installations of PIT tag detectors is underway in the Columbia River basin).
- Costs of mass marking would be born principally by the agencies doing the mass marking
- In the Columbia River, dam passage facilities are being equipped with PIT tag detectors that can record signals from both juveniles and adults so accurate counts can be readily obtained.
- Method would comply with Congressional directives for mass marking of production from federal facilities
- A database for PIT Tag information for the Columbia River system has been designed and is operational (PIT Tag Information System (PTAGIS, See: http://www.psmfc.org/pittag/)
- Existing equipment could continue to be used to mass mark fish.

Disadvantages:

- Costs of tags (PIT tags currently cost ~$2/tag). Tag application costs ~$1/tag. The technology for newer versions of RFID tags that could be used for fish and read tags through water has not yet been developed; however, RFID tags are rapidly being deployed in the aquaculture industry where wet operating environments are common.
- Potential difficulty of tagging small fish (<55mm in length).
- PIT Tag readers: (a) limited distance (<3') at which PIT Tag readers can effectively function in water; (b) metals in the immediate area where PIT Tags are to be read can interfere with operation; (c) while the PIT Tag readers can be very reliable, engineering design work would likely be required when installing stationary PIT Tag readers; for instance, detection rates appear to be affected by weir design and adult swimming behavior in avoiding weirs.

Critical assumptions required for analysis

- For estimation of MSF mortality, no significant additional mortality caused by Mass Marking.

Logistical requirements for implementation

- Tag reader/detectors
- Mass marking would need to be performed by hand clipping

Estimated costs of implementation

- PIT Tags - Costs (~$2/tag). Tag application costs ~$1/tag – Tagging rates have been reported at 250-300 fish/hr. However for certain types of studies (e.g., estimation of mortality rates) or by increasing sampling rates, fewer tags may be required. Per unit cost of PIT tag detection equipment (varies by features). Fixed ~$8500' Hand held data logging type: $1500
- Future versions of RFID tags – undetermined. Current cost of passive tags ($0.20-$0.50).

MAJOR RECOMMENDATIONS

RECOMMENDATION 1. *Substantial improvements must be made in the CWT system to insure that the quality and reliability of collected data are consistent with the increasing demands being placed on these data by fishery managers. Areas requiring attention include quality control/quality assurance, and various sampling design issues including expansion of catch and escapement sampling in areas where little or no sampling currently takes place.*

The Panel's findings indicate that the CWT system should remain the primary stock assessment tool for the CTC and CoTC in the short-term (5-10 years). The Panel recommends that agencies and the entities responsible for data exchange undertake an in-depth review of procedures and methods involved in collecting and reporting CWT data. In addition, the Panel recommends that agencies responsible for tagging, marking, and recovery programs review internal procedures to determine if revisions are necessary to meet objectives for the quality of information to be obtained from CWT experiments, particularly if mass marking and mark-selective fisheries are increased in number and intensity.

Quality Control/Quality assurance.

The utility of the CWT system depends upon interagency reporting that provides ready access to release and recovery data. CWT data are reported using standardized formats and protocols developed through the Pacific States Marine Fisheries Commission's Mark Committee and the Data Standards Sub Committee of the PSC's Data Sharing Committee (PSMFC, PSC). Although guidelines have been developed for utilizing these formats and validation checks have been adopted by entities responsible for housing CWT data, problems with the accuracy of data continue to persist. For example, instances have been encountered where fish are reported as being recovered prior to release, estimates of catch have been reported with leading values truncated resulting in erroneous sampling fractions, unique identifiers for catch samples are not required sometimes making it impossible to associate recoveries with specific sampling strata. Although individual records have unique identifiers, those identifiers are not permanent, making it difficult to construct audit trails and trace sources of discrepancies between different versions of databases. Lastly, agency interpretations of reporting field content and recording are sometimes inconsistent between agencies and over time.

While such problems can be corrected once identified, there are undoubtedly instances where analyses have proceeded without knowledge of underlying errors in the data. Greater attention is needed to improve the quality of data being reported to through the CWT system.

Issues directly involving the tagging program.

Accuracy of number of fish released with and without a tag.

Hatcheries use various methods to account for fish released. A variety of counting methods continues to be used at the hatcheries to estimate release group sizes. The least desirable method, the so-called 'book estimate', involves regular subtraction of the dead fish and is fraught with problems. More commonly, various weight-derived methods are used but these too can have sizeable inherent error (Johnson, 2004). Many hatcheries have turned to the use of fish counters to account for all outmigration, which is an improvement. These methods should be reviewed and improved where necessary. Without accurate estimates of the numbers of fish in release groups, estimates of rates of return, and expansions from tagged fish to total hatchery production will be unreliable.

Treatment of tagged groups.

The indicator tag groups are intended to be representative of the natural production. This will set certain criteria for the age, time and location of release of the tagged group. In addition if the indicator group is a double index tag group, the marked and unmarked members of the tag group must be identical in all ways except for the mark and so there must be no difference in their handling before, during and after tagging and marking. This would include randomizing the selection of fish for the two groups, tag and handle at the same time in an identical manner (except for the tag) and mix and treat identically after tagging.

Reporting of DIT groups.

The reporting of sample and tag recovery data has protocols and criteria set by PSC technical committees, and generally follows these protocols. However in analysis of the DIT data for coho some inconsistencies were found, including inconsistent reporting of mark-selective fisheries and sample methods. The Joint Coho DIT Workgroup found inconsistent reporting of the DIT groups identification information and mark status. This information is necessary for the use of these tag groups for fisheries management.

Issues relating to sampling design.

CWT experiments are conducted with the expectation that data will be collected according to a well-designed and effectively implemented sampling design. Johnson (2004) gives a regional overview of the CWT system, and describes the regional tagging and sampling programs, tagging, sampling and data reporting methods and protocols. He also provides an overview of CWT program issues, including:

- *Lack of Standards for Tagging Levels*
- *Need to Improve Accuracy of Tag Loss Estimates*
- *Unstable Funding for Tag Recovery Programs*
- *Inequitable Cost Burden upon Recovery Agencies*
- *Sampled Harvest from Multiple Catch Areas*
- *Unreported and Misreported Harvest Bias*
- *Need for a Solid Statistical Foundation*
- *Are Hatchery Indicator Stocks Representatives of Wild Stocks?*

- *Error in Estimates of the Number of fish Released and Under-Sampling of Fisheries and Escapement*
- *Lack of Uniformity in Electronic Sampling*
- *Impact of 'Blank Wire' Tags on Recovery Agencies*
- *Need to Estimate and Report 'Imputed Mortalities' in Mark-selective Fisheries*

General standards have been established for numbers to tag (e.g., 200,000 for chinook indicator groups, ~40,000 for Puget Sound coho salmon indicator stock groups), but the underlying bases for these standards are not consistently documented, with some exceptions (e.g., Scott et.al. 1992). More generally, agencies have rarely undertaken the effort to develop a formal sampling design to evaluate whether or not these standard release group sizes can be expected to produce data sufficient to provide statistics of desired reliability.

Similarly, standards have been set for sampling rates to recover CWTs (e.g., 20% in fisheries, 100% in hatcheries). Basically, the sampling system is a random stratified design with each stratum representing a fishery, area and time period or an escapement location, hatchery or natural spawning areas (see Johnson, 2004 for description). The intent of the stratification is that all fishery-area-time periods or escapement locations where tagged fish are present will be sampled, and that within a stratum the samples will be representative of the sampled population.

Catch sample strata must be defined in a manner that allows estimation of the sampling fraction. There are some issues that need attention in this area. Harvest is sometimes sampled from multiple catch sample areas or gears, with no way of separating the sample to the appropriate area or gear and calculating a sampling fraction. Such samples are not contributing to the useable management database. Catch sample area-periods should coincide with management periods, e.g., if a mark-selective fishery is implemented, it must be sampled as a catch-sample stratum that is separate and independent from NSF area-periods.

The 1999 report of the Data Sharing Committee noted that a sizeable percentage of the catch sample strata for commercial fisheries harvesting chinook did not meet the minimum standard of 20%. Ensuring adequate sampling fractions for sport fisheries, particularly in freshwater areas, remains problematic given agency budget limitations. Unreported catches occur in every fishery, and misreporting is a problem in some fisheries (Johnson, 2004). These problems include fish taken home for personal use, some subsistence and ceremonial catches, incidental catches of one species sold as the target species in a fishery and direct "over the bank" sales of fish. As pointed out in the Panel's Finding 2, lack of sampling in fisheries and in escapement seriously comprises the quality of the catch and recovery data and biases estimates of key statistics like fishery exploitation rates. The sampling program should provide complete coverage of all fishery and escapement locations where CWT-tagged fish are expected to be present.

In addition to issues relating to stratification, the methods used to sample the catch has become a matter of increasing concern with the institution of MM and MSF. The switch to electronic sampling has not been fully implemented throughout the Pacific coast.

Alaska and California continue to rely on visual sampling for the adipose clip to recovery CWTs. Washington and Idaho rely fully on electronic sampling. Oregon and Canada use a variety of sampling approaches. There is an increasing lack of sampling and/or processing of unmarked and tagged fish, even in NSFs, particularly in Canada and Oregon. This introduces an additional source of bias in the use of DIT data for estimation of exploitation rates.

Finally, natural escapements are often not completely sampled for straying. The estimation of tagged harvest and escapement depends on expansion to the total harvest and escapement. Reliable counts or estimates of these totals must be available.

In light of increased allocations of harvest to sport fisheries and increasing escapements due to reductions in fishery impacts, sampling efforts need to be improved in these areas in order to avoid potential biases in estimated exploitation rates.

The CWT program will remain the major source of management information for some years to come. In order to maximize its utility, it is imperative that agencies pay attention to meeting the criteria set by the sampling design, tagging and sampling protocol and database requirements. Simply stated, the CWT program needs a tune-up.

It is imperative that agencies maintain this coast-wide system which provides the only consistent source of stock, age and fishery specific information under the current fisheries management regime. Towards this goal, agencies should implement reviews of their tagging and sampling program and ensure that the quality of these programs meets the standards of the sampling design and protocols set by the PSC.

Citation.

Johnson, J.K. (2004) Regional Overview of Coded Wire Tagging of Anadromous Salmon and Steelhead in Northwest America. Pp.40 Paper updated from 1989 to current year 2004 . Regional Mark Processing Center, Pacific States Marine Fisheries Commission.

Joint Coho DIT Analysis Workgroup. 2003. Analysis of coho salmon double index tag (DIT) data for the brood years 1995-1997. Northwest Fishery Resource Bulletin. Project Report Series No. 12. pp. 160.

Joint Technical Committee on Data Sharing. 1999. Report on the 1994 Status of the Coast-wide Coded Wire Tag Database. TCDS (99)-1. December, 1999.

Scott, J.B., S.D. Moore and R.A. Moore. 1992. Review of the chinook exploitation rate indicator stock program for the Washington coast and Puget Sound. Manuscript. Pp.111.

RECOMMENDATION 2. *Explicit criteria should be developed for the precision of statistics to be estimated from CWT recovery data. New guidelines for CWT release group sizes and fishery and escapement sampling rates should be based on these explicit criteria.*

Over the past decade, the information provided by the CWT system has deteriorated. The reasons can be divided into two broad categories. First, there has been a reduction in the number of CWTs actually returned from fisheries, primarily due to: (a) a reduction in funds available for catch sampling and tag-recovery programs; and (b) reduced overall catch rates during a period of reduced ocean survival and reduced fishery exploitation rates. In the absence of other problems, these concerns lead to estimates that are still unbiased, but are of poorer precision (i.e., higher uncertainty).

The Panel received a report "Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management" (Alexandersdottir et.al., 2004) which examined these issues in detail. As noted by the technical report (Section 3.3.1), *"[I]mproving the precision of estimates of tagged fish harvest and in escapement and of exploitation rates, requires increasing the number of tagged fish recovered ... can be done by increasing the number tagged, increasing the number sampled, increasing the harvest rates, or redefining fishery resolution"*.

By comparing the precision of estimates from single and double index tagged groups, the report found that a doubling the number of tags recovered leads to a reduction in uncertainty by a factor of $\sqrt{2} = 1.4$. Similarly, a doubling of the sampling effort in the fishery (the current target is 20% of the catch) also leads to the same $\sqrt{2} = 1.4$ reduction in uncertainty. Thus, to halve the uncertainty in an estimate, either a quadrupling of tagging or sampling effort is required. Reduced ocean survival is also expected to have the same impact as this leads to fewer fish available for sampling.

The report also examined the impact on bias when not all locations are sampled. As the report notes, *"[A]ny estimates of exploitation rates made using tag groups where there are tagged fish that were harvested or escaped, but not included, will be biased. The impacts ... are two-fold... where a fishery is not completely sampled, the SER [simple exploitation rates] for stocks...with unreported tagged fish will be underestimated or zero ... the SER for those same stocks will be overestimated in all other fisheries"*. The report's Table 3-6 illustrates the size of the potential bias. For example, if the unsampled fishery comprised 50% of the total exploitation, then the remaining estimates of exploitation would be biased upward by 100%, i.e., effectively doubled. This lack of sampling also affects the estimates of precision leading to increased levels of uncertainty as well. A larger proportion of mortality is due to non-sampled fisheries such as "over the bank sales" and "recreational fisheries". In the absence of other problems, this can lead to biases in the estimates, i.e., the reported exploitation rates overestimate the true exploitation rates because the cohort size is underestimated.

The report summarizes the relative uncertainty of exploitation rates as a function of fishery resolution. As the fishery resolution becomes finer, the number of tags recovered

in any one stratum may decrease, resulting in smaller exploitation rates. As the number of tags decreases, the uncertainty surrounding these estimates of exploitation rates increases. For example, if the simple exploitation rate of a stock is under 1%, the percent standard error is well over 50% which implies that a 95% confidence interval for the actual exploitation rate is approximately ±100%, i.e., if the reported exploitation rate is 0.5%, the actual exploitation rate could be as high as 1%. If the simple exploitation rate is over 5%, then the relative standard error is on the order of 25-30%.

The overall picture is not very reassuring – lower sampling rates, lower ocean survival, and finer fishery resolution all conspire to increase uncertainty in the estimated exploitation rates. Since the late 1970s when the CWT system was set up, annual ocean fishery exploitation rates for chinook salmon have fallen from as high as 80% to current levels between 15% and 20%. Just this single change implies that the uncertainty in the estimates has increased by a factor of 2 over this period.

The unresolved question is how much precision is required? The Pacific Salmon Treaty is silent on this matter except that there are expectations that this will be addressed. For example, Chapter 3.1.b.v of the Pacific Salmon Treaty states that:

"[Chinook Technical Committee shall]... recommend standards for the minimum assessment program required to effectively implement this Chapter, provide information on stock assessments relative to these standards and to recommend to the Commission any needed improvement in stock assessments.."

Similarly, Chapter 5.6.d.4 states that the Coho committee shall:

"...estimating fishing mortality and spawning escapements with desired levels of precision and accuracy ..."

And, the MOU of 13 August 1985 states that:

"...The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessment and fishery evaluations..."

The CTC has recently developed a draft report, "Data Standards for Statistics used by the Chinook Technical Committee" dated February 2005. In this document, proposals for minimal standards are proposed, but this document is not yet official.

For example, the report states *"... tagging programs ... should be sufficient to provide estimates of total brood year exploitation rates with a 95% confidence interval ±5 percentage points of the estimated percent exploitation"*. If the simple exploitation rates for Grovers and Soos Creek presented in Table 3-3 of the Technical Review report are typical, then the average exploitation rate in approximately 60 fisheries was around 1% in each fishery, with percent standard errors of around 50% for each fishery. (See also Table 4.1 of the Technical Review with a similar summary). The total exploitation rate over the 60 fisheries will have a percent standard error of approximately $50\% / \sqrt{60} = 7\%$

(assuming that the errors in each fishery are not correlated) and absolute standard errors of 7% x 60% = 4 percentage points. The approximate 95% confidence interval is then around ±8 percentage points, and does not meet the proposed standard. To meet the proposed standard, the number of tags recovered needs to be increased by a factor of about 2.5 (either increased tagging or increased sampling).

As a second example, the proposed standards state *"... the coefficients of variation (cv) for point estimates [of escapement] should not exceed 20% on average across years."* Appendix Table VII of the Technical Report shows that the cv of the estimated escapement for Big Qualicum River easily meet this target (cvs on the order of 5-10%), and the CVs for the estimated escapement for the Kitsumkalum River are close to target (cvs on the order of 15-25%),

The standards for specific stocks or groups of stocks were not yet developed in the draft report on standards received by the Panel. The Panel was unable to determine how these standards were developed. For example, with a relative standard error of 50% in year-to-year estimates of exploitation, a power analysis of trend indicates it would take over 10 years to have an approximate 80% power to detect a 10% change/year in exploitation rates! Is this sufficient for management purposes?

It is clear that the precision of estimates based on CWT recovery data has deteriorated over time. A careful review needs to be done to ensure that estimates provided are still adequate for management purposes. This may require increasing sample sizes for some cohorts and modifying sampling efforts in certain fisheries. As in Recommendation 3, decisions on release size-sample requirements and fishery sampling efforts should be decided on the basis of precision needed to make specific management decisions (as specified by the Treaty). In the long term, this can be embedded in a decision-theoretic framework that balances the need for precision and the limited funds that may be available to expand the CWT system.

Citations

Alexandersdottir, M., Hoffmann, A., Brown, G. and P. Goodman. 2004. Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management. Presentation to Expert Panel, June 7-10, 2004 at Workshop on Future of the CWT Program: Challenges and Options

Anonymous (2005). Data standard for statistics used by the Chinook Technical Committee: Draft, dated February 2005 of a report of the Pacific Salmon Commission Chinook Technical Committee.

RECOMMENDATION 3. *We recommend that the utility of a decision-theoretic approach, integrating costs, benefits, and risk into a formal evaluation structure be investigated as a means of prioritizing potential improvements (e.g., measures to improve CWT data – reporting, sample design, and protocol) to the CWT system. The approach should identify the release group sizes and recovery programs required to meet the statistical criteria for CWT recovery data. Sampling programs should include all fisheries, hatcheries, and spawning ground areas where CWT exploitation rate indicator stocks are present.*

Several aspects of the Panel's investigations into the CWT system would benefit from a formal decision-theoretic structure to weigh alternatives and evaluate their relative merits.

- Generally, decision theory is a formal method to integrate knowledge and the values of the decision maker when evaluating the costs and benefits of pursuing alternative courses of action in the face of uncertainty. Decision theory involves the application of a rich collection of methods, procedures, algorithms, and techniques to reveal the consequences of alternatives and provide guidance as to the choice that maximizes utility to the decision maker. Principles of precautionary management employed in fisheries management reflect concepts of decision-theory (see, e.g., Hilborn and Peterman, 1986).

- The design of CWT experiments involves the consideration of many factors, including the number of fish tagged and the costs of sampling and reporting programs. Decisions must be made in the face of uncertainties like survival rates of released fish, levels of fishery exploitation experienced by CWT groups, and the quality of sampling programs conducted by different jurisdictions that may impact the fish throughout their life spans. The fiscal and staff resources that decision-makers will be willing to invest in a particular study depends upon the relevance of the information obtained, the degree of uncertainty that can be tolerated, and the consequences of error.

  These considerations apply equally as well to measures that may be undertaken to improve the capacity of the CWT system to provide data required to support management decisions. The capacity to design CWT experiments and prioritize investments to correct deficiencies and enhance performance of the CWT system would benefit from the development of a formal decision-theoretic framework that would integrate these considerations into a tool that would help inform decision-makers of the costs, benefits, risks of taking or failing to take certain actions.

- The quality of information provided by the CWT system is deteriorating and management uncertainties are increasing as a result. One way to compensate for these problems would be to adjust management targets such as allowable fishery exploitation rates. Such adjustments would involve consideration of risk both to the resource and to the people and industries that depend its utilization. A formal decision-theoretic framework would make the costs and benefits of adopting

precautionary management approaches to accommodate increased uncertainty evident to decision-makers.

Decisions involve alternatives and choices. When making decisions, judgments come into play which weigh uncertainty, costs, and consequences against potential benefits. Uncertainty involves the degree of information available to support the decision – Are the data rich or poor? Is the problem well confined? Costs involve commitment of money and scarce staffing as well as awareness of what alternative uses these resources might be put. Consequences involve consideration of a myriad of factors, usually surrounding the risks of error, but also involving timing. "Ripeness" may dictate when a decision needs to be made as well as the capacity to implement it – politics, in a broad sense, can dictate how worthwhile it is to attempt to undertake an action. Sometimes what may seem like an excruciating choice, both technically and financially, may not be implemented because the political will is lacking.

Decision-theoretic approaches have been extensively employed in business (e.g., industrial engineering, operations research, asset allocation, investment) and government (e.g., military) for several decades. The calculus of probabilities has been extensively studied. Yet decision-theoretic approaches have not been widely applied in fisheries management, even though the need seems obvious. The PSC should consider issuing an RFP to develop a formal model for making decisions involving CWT experiments and investments in system improvements.

Citations

Hilborn, R. and R.M. Peterman. 1986. The development of scientific advice with incomplete information in the context of the precautionary approach. In: Precautionary Approach to Fisheries, Part 2: Scientific Papers. FAO Fish. Tech. Pap. (350/2):77-101.

Howson, C.and P.Urbach. 1998. Scientific Reasoning. The Bayesian Approach. Open Court. Peru, Illinois.

Mack, R.P. 1971. Planning on Uncertainty. Decision Making in Business and Government Administration, Wiley-Interscience, John Wiley and Sons, Inc. New York.

RECOMMENDATION 4. *We recommend completion of a comprehensive survey and statistical analysis of all relevant published and unpublished CWT studies that concern the correspondence between exploitation patterns and rates for hatchery indicator stocks as compared to their natural counterparts. This review should also include new analysis of relevant agency-collected data that have not yet been previously subject to analysis. Recommendations for additional studies should be made if they are judged necessary.*

PSC agreements for chinook and coho are focused on management of natural stocks that are harvested by the fisheries of both countries. The key assumption underlying PSC regimes for chinook and coho is that the selected hatchery indicator stocks are representative of their associated natural stocks. Fishery impacts on natural stocks are largely derived from data collected for surrogates, usually specific groups of artificially propagated and tagged fish, based on origin of the spawning stock and rearing/release strategies. Estimates generated from cohort reconstruction of these surrogates (e.g., maturation rates, fishery-age exploitation rates) are presumed to apply to associated naturally spawning populations. (The validity of this assumption is critical for interpretation of CWT recovery data, but would also be critical also for interpretation of tag recovery data generated by any other tagging methodology such as otoliths or the proposed FPG methodology.)

CWT data to permit direct estimation of exploitation rates for progeny of naturally spawning populations are sparse. Results of wild smolt tagging experiments in Puget Sound, Southern British Columbia, and the Washington Coast support the belief that hatchery indicator and wild coho stocks are subjected to similar fishing patterns. This relationship is less clear for chinook, but tagging experiments with progeny from wild and hatchery brood stock suggest that the use of indicator stocks is reasonable, but not certain.

The Panel recommends that the PSC solicit proposals for research studies[4] directed at testing the degree to which selected hatchery releases are representative of associated natural production. The research should be designed to test the assumption that selected hatchery surrogates and associated natural stocks undergo the same patterns of migration, maturity, and exploitation. Direct validation of the key assumption that hatchery fish can be used to represent naturally spawning fish through CWT methods can be challenging and costly because of the difficulty of tagging and recovering sufficient numbers of naturally produced fish. Genetic stock identification (GSI) methods combined with data gathered from CWT programs currently hold the most promise. The following examples illustrate potential ways in which GSI and CWT data could be integrated.

Example 1. CWT recoveries could be correlated with stock composition estimates derived from GSI studies to determine if the two groups are encountered in the same fisheries in similar concentrations.

[4] The studies could perhaps be conducted as part of a larger "grand experiment" (Appendix B, Recommendation 8).

Example 2. GSI-based estimates of stock composition could be used to validate CWT-based stock compositions derived from the mixed-stock model employed for coho run reconstruction methods.

Example 3. GSI estimates of stock composition of sub-legal fish could be employed to test the validity of assumption-based approaches that are based on recoveries of legal-sized fish.

RECOMMENDATION 5. *Evaluate the utility of band-recovery or state space modeling approaches to estimate exploitation rates and maturation probabilities from cohort reconstructions based on CTW recovery data. These alternative modeling schemes may allow information from multiple cohorts to be combined to improve estimators compared to current single-cohort methods for which each cohort is treated independently.*

Currently, exploitation rates are estimated through cohort reconstruction methods applied to individual cohorts and there is little or no pooling of information across cohorts. It could be argued that the parameters are sufficiently different across cohorts and across years that such pooling is not realistic. However, summary tables of the precision of estimates for parameters such as the simple exploitation rates (see Table 3-1 of the Technical Review Document, Alexandersdottir et.al., 2004) show that many of the 95% confidence intervals are ±100% of their estimated values so that any sensible model that assumes equal parameters over time will be consistent with the data.

There are two common types of models that may be useful in this context. The first, band-recovery models, were developed to deal with returns of tags from harvested waterfowl. In this context, the tag-reporting rate was unknown which reduces somewhat the level of detail possible in estimating harvest rates, but with additional information, these problems have been overcome. It is unclear to the Panel if these class of models has been considered by the PSC. Other agencies have investigated their use. For example, Hankin and Mohr (1993) investigated the use of Brownie models for data from two hatcheries in California in a report for the US Fish and Wildlife Service.

The second method is the use of state-space models. These models have many similarities with Bayesian models in that the underlying (unobservable) process is "generated" based on observed data. Models where annual variation in parameters is modeled by sampling from a common distribution are easily accommodated. The Panel did not receive any information indicating that these methods have been assessed for use by the PSC.

As a cautionary note, no amount of statistical wizardry can attempt to fix problems caused by inadequate release sample sizes, non-sampling of critical elements of the life history, or inadequate sampling of the fisheries.

Band-recovery models.

The current CWT estimation methods rely upon cohort reconstruction methods with apparently separate parameters for each fishery operating on each age class of a cohort. It appeared to the Panel that each cohort is analyzed separately, and that no pooling of information across cohorts takes place. Refer to Hankin and Mohr (1993) for an example of the use of Brownie models for data from two hatcheries in California.

The estimation of survival and harvest is a common problem in waterfowl studies. Brownie et. al. (1985) provides a comprehensive review of the analysis of band-recovery data. The key features of their analysis are commonalities of parameters across cohorts.

For example, consider a three cohort, 4 year of recovery study. The data can be arranged into a 3x4 triangular array below (Table 7). Here N_i represents the number of animals tagged and released each year, and R_{ij} represents the number of animals released in year *i* and recovered in year *j*.

Table 7. Statistics collected for the Brownie model

Number released	Recovered in year 1	Recovered in year 2	Recovered in year 3	Recovered in year 4
N_1	R_{11}	R_{12}	R_{13}	R_{14}
N_2		R_{22}	R_{23}	R_{24}
N_3			R_{33}	R_{34}

The expected number of recoveries can be written in terms of the year specific recovery and reporting rates (f_i) which is defined as the probability that the animal is harvested, its tag recovered, and returned to the recording office; and S_i, the probability that the animal survives from year *i* to year *i* + *1* (Table 8)

Table 8. Expected recoveries using the formulation of Brownie et al (1985).

Number released	Expected Recovered in year 1	Expected Recovered in year 2	Expected Recovered in year 3	Expected Recovered in year 4
N_1	N_1f_1	$N_1S_1f_2$	$N_1S_1S_2f_3$	$N_1S_1S_2S_3f_4$
N_2		N_2f_2	$N_2S_2f_3$	$N_2S_2S_3f_4$
N_3			N_3f_3	$N_3S_3f_4$

Note that a common survival rate (S_i) and recovery rate (f_i) occur across cohorts. Brownie et. al. (1985) provide MLEs of the parameters based upon these models. There are a number of advantages of this type of modeling compared to the cohort reconstruction methods currently used: (a) Only the actual number of reported CWT would be used – it is not necessary to expand the reported number by the search fraction; (b) non-reporting of CWT is handled properly; (c) it is not necessary to follow a cohort until the end of its age to make inference on earlier years.

It has been suggested that the Brownie model needs to be modified to account for MSF and NSFs and for survival post-fishery, but prior to the next years catch. Consider a simple example, where a mark-selective fishery follows a selective fishery. (Other configurations are possible, for example the two fisheries could be simultaneous or in the opposite order which will affect the model development). The notation must be extended a bit to distinguish between harvest and reporting. Let MS_i represent the probability of catching a fish in a mark-selective fishery; NS_i represent the probability of catching a fish in a NSF; R_i represent the reporting rate; and P_i represent the probability of surviving after fisheries to the start of the next year. [In the previous examples, the probability of catching a fish and reporting its CWT is all combined into the f_i terms.] The matrix of expected recoveries would appear as in Table 9.

Table 9.	Expected recoveries when survival is to be partitioned into various components.	
Number released	**Expected Recovered in year 1**	**Expected Recovered in year 2**
N_1	$N_1(NS_1 + (1-NS_1)MS_1)R_1$	$N_1((1-NS_1)(1-MS_1)P_1)(NS_2 + (1-NS_2)MS_2)R_2$
N_2		$N_2 (NS_2 + (1-NS_2)MS_2)R_2$

Such a formulation would indicate that only the product of fishing (MSF andNSF) survival and natural post-fishing survival could be estimated. However, it may be possible to resolve some of these issues using post-release stratification models of Schwarz et. al. (1988). These post-release stratification models allow for different recovery types (in this case, NSF and MSF) and may be able to separate out the various components of mortality.

The key to the Brownie et. al. (1985) models is the common parameters across cohorts. When multiple cohorts are considered, it may not be reasonable to assume that the exploitation rates will be the same for all ages - i.e., the age 1 fish from second cohort will be exploited at the same rate as the age 2 fish from first cohort because these are different sizes of fish and their vulnerability to the fishery can be expected to vary because of regulatory measures like size limits and migration patterns. While the above models have mostly been structured in terms of year-specific fisheries, the Brownie type models have also been extended in terms of age-structured models (e.g. Brownie et. al., 1985; Brownie and Robson, 1976). They showed that it is possible to estimate age- and year-specific survival rates if ages of the fish are known, as would happen in a CWT study. Brooks et. al. (1998) presented an age-structured model with multiple fisheries as well. Furthermore they state *"... the formulas presented were demonstrated for two user groups, ... clearly be applied to any number of user groups... be used when data on a multiple user fishery are available provided the tag returns are recorded separately and an independent estimate of report rate is available."*

Finally, Hankin and Mohr (1993) considered additive models where the effects of year and age are additive, i.e., parallel but not coincident patterns of mortality by year for separate cohorts. Again, these simplified models may be able to resolve some of these confounding issues.

The Brownie et. al. (1985) suite of models has been extended in various ways. For example, Schwarz et. al. (1993) use this type of data to estimate migration rates; Brooks et. al. (1998) use post-stratification to deal with different fisheries and user groups in each year (e.g. MSF and , NSF); Hearn et. al. (1998) showed how to estimate reporting rates and pre and post season mortalities; Hoenig et. al. (1998a) allowed incomplete mixing of newly marked and previously marked animals; and Hoenig et. al. (1998b) incorporated fishing effort information into the study.

State-space models.

Another class of models that has been successfully used in the analysis of tag returns are state-space models. Here the system is partitioned into two different processes – the underlying physical model (aging, movement, etc), and the observation process (the fishery) which takes the underlying population numbers and provides some data (number of tags recovered).

Typically, state space models separate randomness into two components – process and measurement error. Process error would describe the fact that movement, survival etc. are random events. For example, if the survival rate is 80%, then, it is highly unlikely that exactly 4 of every 5 fish survive. There will be variation in the actual annual survival rates around this "average" value. Measurement error is analogous – even if 3% of fish in a stock are from a specific stock, it is highly unlikely that a sample from the stock will have exactly 3% of its fish from that stock. The major advantage of separating these two types of errors is mostly conceptual, but there are some advantages in the separation that become apparent when estimation takes place.

Parameter estimation takes place using maximum likelihood estimation for simpler models that use a normal error structure or Bayesian methods that allow more flexibility in error structures and more importantly allow for a much wider class of models with fewer free parameters to be fit. This reduction in the number of parameters that need to be estimated is crucial in improving precision from small numbers of recoveries.

State-space models have been used to model salmon movement and harvest (e.g., Newman 1998; Newman 2000) and are gaining increasing recognition and usage as an appropriate tool for modeling sequential fisheries data (e.g., Schnute 1994; Reed and Simons, 1996). When state-space modeling is used for sequential fisheries, Newman (2000) and others argue that the additional structure placed on the cohort specific parameters is a reasonable way to deal with annual variation in the parameters. This can happen in two ways.

First, parameters may be forced to be equal across cohorts or years. For example, annual maturation rates may be equal for all cohorts for all years. This provides a means for cohorts to borrow strength from other cohorts about parameters. For example, a cohort with a relatively small number of tag recoveries due to reduced effort may have very imprecise estimates of parameters if analyzed in isolation, but if the pattern is similar for other years, it can be combined with information from the other cohorts.

Second, random effect models can be relatively easily fit using Bayesian methods. These allow for year and cohort variation but in a structured fashion. For example, it may not reasonable to assume that annual maturation rates are fixed over time and cohorts, but it may be more reasonable to assume that the distribution of annual maturation rates across time and cohorts comes from a specified distribution that depends upon a small number of parameters. Rather than trying to estimate each individual parameter for every combination of time and cohort, only the parameters (typically the mean and variance) that describe the variation over time and cohorts need to be estimated. For example,

Newman (2000) assumed that annual variation in the cohort-specific parameters could be modeled from a hyper-distribution (analogous to what happens in Bayesian models). He presented an example of six cohorts from the Humptulips hatchery from1984 to 1989 that were analyzed together in this fashion.

As pointed out by a reviewer, this technique may also be applicable to combining information from multiple paired release treatments that are simultaneously applied to a lot of stocks that share some regional fishery impacts but not others (see, e.g., Deriso's (Desriso et.al.,2001) model for Columbia River Chinook survival using data from multiple stocks that pass through variable numbers of dams). The WCVI-Juan de Fuca fishery area, where some coho and Chinook stocks are and others are not subject to big recreational and troll interceptions, or river fisheries where fish migrate through variable numbers of sequential recreational fishing areas, are examples of situations where these kinds of "shared effects" procedures might be useful.

Finally, Newman (2000) concludes that the state-space models can be extended to allow for multiple competing gear types and more complex movement patterns.

Citations

Alexandersdottir, M., Hoffmann, A., Brown, G. and P. Goodman. 2004. Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management. Presentation to Expert Panel, June 7-10, 2004 at Workshop on Future of the CWT Program: Challenges and Options

Brooks E.N., Pollock K.H., Hoenig J.M. and Hearn W.S. (1998) Estimation of fishing and natural mortality from tagging studies on fisheries with two user groups. *Canadian Journal of Fisheries and Aquatic Sciences,* **55,** 2001-2010.

Brownie C., Anderson D.R., Burnham K.P. and Robson D.S. (1985) *Statistical inference from band recovery data :a handbook.* Washington:U.S. Dept. of the Interior, Fish and Wildlife Service.

Brownie C. and Robson D.S. (1976) Models allows for age-dependent survival rates for band-return data. *Biometrics,* **32,** 305-323.

Deriso, R. B., D.R. Marmorek, and I.J. Parnell. 2001. Retrospective patterns of differential mortality and common year-effects experienced by spring and summer chinook salmon (*Oncorhynchus tshawytscha*) of the Columbia River. Can. J. Fish. Aquat. Sci. 58: 2419-2430.

Hankin, D.G. and Mohr, M.S. (1993). New methods for analysis of coded-wire tag-recovery data. California Cooperative Fishery Research Unit Agreement No. 14-16-0009-1547, Research Work Order no 32.

Hearn W.S., Pollock K.H. and Brooks E.N. (1998) Pre- and post-season tagging models: estimation of reporting rate and fishing and natural mortality rates. *Canadian Journal of Fisheries and Aquatic Sciences,* **55,** 199-205.

Hoenig J.M., Barrowman N.J., Hearn W.S. and Pollock K.H. (1998a) Multiyear tagging studies incorporating fishing effort data. *Canadian Journal of Fisheries and Aquatic Sciences,* **55,** 1466-1476.

Hoenig J.M., Barrowman N.J., Pollock K.H., Brooks E.N., Hearn W.S. and Polachek T. (1998b) Models for tagging data that allow for incomplete mixing of newly tagged animals. *Canadian Journal of Fisheries and Aquatic Sciences,* **55,** 1477-1483.

Newman K.B. (2000) Hierarchic modelling of salmon harvest and migration. *Journal of Agricultural Biological and Environmental Statistics,* **5,** 430-455.

Newman K.B. (1998) State-space modelling of animal movement and mortality with application to salmon. *Biometrics,* **54,** 1290-1314.

Reed W.J. and Simons C.M. (1996) Analyzing catch-effort data by means of the Kalman filter. *Canadian Journal of Fisheries and Aquatic Sciences,* **53,** 2157-2166.

Schnute J.T. (1994) A general framework for developing sequential fisheries models. *Canadian Journal of Fisheries and Aquatic Sciences,* **51,** 1676-1688.

Schwarz C.J., Burnham K.P. and Arnason A.N. (1988) Post-release stratification in band-recovery models. Biometrics, 44, 765-785.

Schwarz C.J., Schweigert J. and Arnason A.N. (1993) Estimating migration rates using tag recovery data. *Biometrics,* **49,** 177-194.

RECOMMENDATION 6. *To provide greater assurance that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSFs.*

Uncertainty concerning the accuracy of CWT-based statistics is affected by the number of tags released, fishery exploitation rates, and sampling programs for catches and escapements. The significance of increased uncertainty depends upon the management question to be addressed and the level of precision required and the sources of error contributed by the CWT data and the assumptions employed in their analyses. Uncertainty has increased in recent years as exploitation rates have decreased, budget pressures have affected marking and sampling programs, and more of the fishing mortality is being attributed non-landed losses under programs such as mass marking and mark-selective fishing.

While uncertainty has increased, harvest managers are requiring CWT-based estimates of fishery exploitation rates at ever finer levels of resolution in an attempt to address stock-specific concerns. Current management processes, however, rarely include consideration of uncertainty in the development of fishery management plans. Consequently, decision-makers are not being adequately informed about potential risks to their ability to achieve resource conservation objectives.

The Panel recommends that fishery managers explicitly consider uncertainty in the development of harvest management plans. The manner in which uncertainty is accommodated within management will depend upon the risk tolerance of decision makers. Recently, the concept of *precautionary management* is being embraced in both Canada and the Untied States. This concept is being framed in terms of three basic factors: (1) the need to make decisions; (2) the risk of serious or irreversible harm to the resources sustaining the fishery; and (3) the lack of full scientific certainty (Mace and Gabriel, 1999)

This can be accomplished through a variety of methods, such as the use of conservative estimates and forecasts of abundance, biased assumptions in impact analyses (e.g., above average contact or release mortality rates), or the establishment of buffers to increase the likelihood of achieving management objectives. The SFEC (2002) presented a set of figures to illustrate how buffers could be employed in establishing management targets (reproduced here for convenience in Figure 11). In Figure 11a, the management target exploitation rate is depicted by the vertical line while the degree of uncertainty (from all sources) about target is indicated by two curved lines (The thin line represents the variability about an exploitation rate that is estimated with greater precision than the thick line). In Figure 11b, the shaded area under the curves indicates the estimated probability that an exploitation rate estimate will exceed the management target (the shaded areas reflect equal probabilities). Figure 11c illustrates how the target for management can be set to ensure that the exploitation rate achieved is below an established upper limit with an estimated probability of compliance (the area under the curve to the right of the

vertical dashed line). With greater uncertainty, the distance between the target value and the upper limit will increase. Thus, the target exploitation rate must be shifted further to the left (lower) to ensure the same estimated probability of compliance (Figure 11d). The difference between the two target values (bold arrow) represents the cost due to increased uncertainty and a specified level of compliance; for example, reduced fishing mortality and catch.

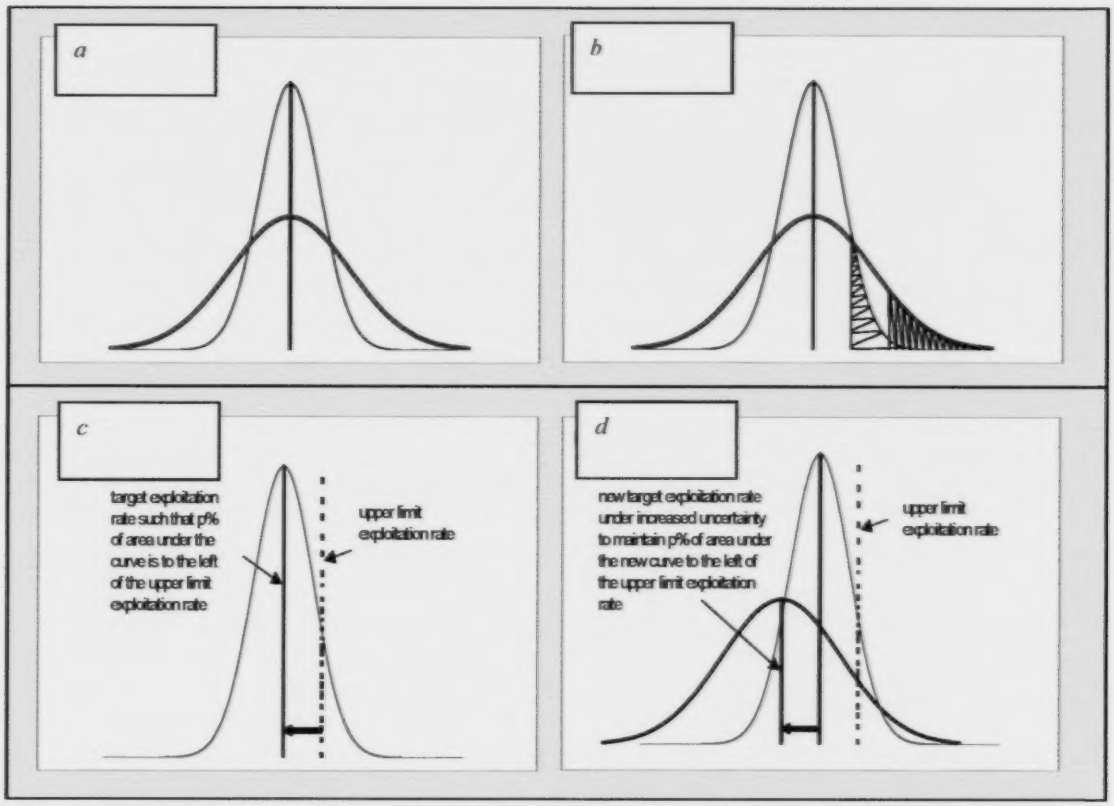
Under management measures like mark-selective fisheries, uncertainty in exploitation rates of unmarked-fish will increase due to loss in precision and introduction of new biases. While it is possible to compensate for reductions in precision by increasing tagging levels or sampling rates, bias will not be reduced.

Shaded areas under the curves (Figure 11b) are equal portions of the two distributions, and indicate the probability that an estimate will exceed a given value. With more uncertainty, the upper bound is at a larger value in the tail of the distribution.

Citations

Mace, Pamela M. and Wendy L. Gabriel. 1999. A Framework for the Application of Precaution in Science-Based Decision Making About Risk. July 25, 2003. Available from http://www.pco-bcp.gc.ca/ In: Evolution, Scope, and Current Applications of the Precautionary Approach in Fisheries. NOAA Tech. Memo. NMFS-F/SPO-40.

SFEC. 2002. Investigations of Methods to Estimate Mortalities of Unmarked Salmon in Mark-Selective Fisheries through the use of Double Index Tag Groups. SFEC(02)-1. February, 2002.


a
b
c
target exploitation rate such that p% of area under the curve is to the left of the upper limit exploitation rate
upper limit exploitation rate
d
new target exploitation rate under increased uncertainty to maintain p% of area under the new curve to the left of the upper limit exploitation rate
upper limit exploitation rate

Management target (dashed vertical line, in c) is set to guarantee that the goal (solid) is met within an established probability of compliance (i.e., we define a "buffer" zone)

With greater uncertainty, the goal (solid, left solid line in d) is shifted to the left to ensuring the same probability of compliance. Then the arrow between goals (i.e., the solid lines for each distribution) is the COST ... in fish, $, etc.

Figure 11. Management targets with increasing uncertainty

RECOMMENDATION 7. *The Panel has conducted a preliminary evaluation of a number of potential enhancements to the basic CWT system and analytical methods that address the complexities introduced by MM and MSFs. This evaluation indicates that no single solution will provide precise and accurate estimates of the stock-specific mortality of unmarked fish over all types of MSFs. Instead, we recommend an approach in which marking, tagging, and analytical methods are linked to the anticipated intensity of mark-selective fisheries .*

We suggest that the SFEC, or other group appointed by the PSC, evaluate the relative performance and cost of alternative approaches to estimate MSF impacts at different levels of fishery intensity (proportion of marked fish taken in fishery) for both chinook and coho salmon. The group should also be charged with developing specific recommendations for both threshold levels (quantitative criteria for determining when intensity is "low", "moderate", or "high", Table 10) and specific methodologies, including marking, tagging, and analytical methods for estimating MSF exploitation rates on unmarked stocks.

The precision of estimates of stock and fishery-specific exploitation rates is often low because relatively few CWTs are recovered in a given fishery strata (see Introduction). Small numbers of recoveries may occur for many reasons, including the release of an insufficient number of tagged fish, poor survival, a low sampling rate, poor survival, too fine a fishery stratification, or simply the fact that few fish of that stock migrate through a particular fishery stratum. With few recoveries, estimates of stock and fishery-specific exploitation rates are highly uncertain. Analyses presented to the Panel (Alexandersdottir et.al. 2004) indicate that an exploitation rate with a point estimate of 5% is likely to have a 95% confidence interval that ranges from less than 2% to more than 8% (assuming normal distribution and Percent Squared Error (PSE) > 30%).

When fisheries are conducted under mark-retention restrictions. estimates of exploitation rates for unmarked fish become more uncertain (due to the lack of direct sampling of fish believed to be representative of a given stock) and bias (due to assumptions involved in estimation methods). However, the practical effect of bias in the estimate of the exploitation rate on unmarked fish could be small relative to the uncertainty already inherent in the estimate of the exploitation rate for marked fish (assuming that the bias is relatively small when evaluated relative to the precision of the estimate). The bias introduced by MSFs will depend on many factors, including species and stock-specific biological characteristics, the location, timing, duration, and intensity of the MSFs, the method for estimating the mortality of unmarked fish, the release mortality rate, and the dispersion rates of fish between geographic areas with and without MSFs.

Table 10. Conceptual approach for linking marking, tagging, and analytical methods to the anticipated intensity of selective fisheries. Estimation methods referenced are described in greater detail in Table 11.

Selective Fishery Magnitude	Tagging and Marking	Estimation Method for Unmarked Mortalities in Selective Fishery
Low	CWT-based indicator stock program with single tag code per indicator stock.	Method 1. Multiply CWT recoveries of adipose-clipped fish by selective fishery release mortality rate.
Moderate	Option A. CWT-based indicator stock program with double-index tagging (DIT).	Method 2. Multiply recoveries of marked fish by mark-selective fishery release mortality rate and the ratio of the unmarked to marked component of the DIT at release.
	Option B. CWT-based indicator stock program with double-index tagging (DIT).	Method 3. Total MSF mortality derived from differences in age-specific escapement rates (or terminal run) of marked and unmarked fish. Mortality allocated to individual fisheries based on distribution of recoveries of marked fish.
High	Option A. CWT-based indicator stock program with double-index tagging (DIT) and otolith marking.	Method 3. Total MSF mortality derived from differences in age-specific escapement rates (or terminal run) of marked and unmarked fish. Mortality allocated to individual fisheries based on sampling of otolith marked fish in paired fishery.
	Option B. CWT-based indicator stock program with double-index tagging (DIT) and otolith marking.	Method 4. Multiply encounters of marked fish in mark-selective fishery by ratio of adipose clipped and unclipped fish with otolith marks in a paired NSF.

Three levels of MSF impact (low, moderate, and high) are generally described below.

Selective Fishery Magnitude is "Low".

When exploitation (impact) rates on unmarked salmon in individual mark-selective fisheries are low, it is unlikely that accurate estimates of stock-age-fishery specific exploitation rates could be obtained under any reasonable scenario of DIT release group sizes and sampling programs. Even when cumulative impacts considered over all MSFs are small, expected differences between age-specific escapement rates of DIT pairs of

hatchery salmon released with and without an identifying mass mark are also unlikely to be detectable. The methods proposed in Appendix A for estimating total non-landed mortalities from DIT releases or other strategies suggested in Appendix F would not perform well under such circumstances. When exploitation rates and overall impacts are "low", we instead recommend imputation of non-landed mortality impacts using assumed values for non-landed mortality rates and estimated exploitation rates for marked fish based on cohort reconstruction methods applied to a single CWT release group.

Hoffmann and Alexandersdottir (2004) employed simple simulations to examine the potential bias that might be introduced by use of imputation methods. Results from the simulations for age 4 fish indicated that bias in estimated mortality of unmarked fish estimated from λ_i^{rel} increased with the harvest rate in the selective fishery. On an absolute scale, the bias is less than 1% for harvest rates of up to 30% applied on an annual basis. The PSE for an exploitation rate of 2% is likely to be in the range of 40%-90% which, depending on the assumptions for the distribution of the exploitation rate, is likely to result in a confidence interval that is substantially greater in breadth than the bias.

Selective Fishery Magnitude is "Moderate"

When exploitation (impact) rates on unmarked salmon in mark-selective fisheries are moderate individually and in overall impact, if release group sizes are sufficiently large, there should be a detectable difference between age-specific escapement rates of pairs of hatchery salmon released with and without an identifying mass mark. Under these circumstances, we believe that the proposed cohort reconstruction methods (Appendixes A and F) should be used for estimating total non-landed mortalities at age. Various algorithms could then be used to allocate these total mortalities across individual mark-selective fisheries. For "moderate" selective fishery impacts, these methods should produce better estimates than imputation because (a) non-landed mortality rates are not assumed known, and (b) estimated total non-landed mortalities should be fully consistent with recovery data for marked and unmarked release groups.

Selective Fishery Magnitude is "High"

When exploitation (impact) rates on unmarked salmon in mark-selective fisheries have "high" overall impact, it may make sense to explore methods that supplement recovery data by at-sea sampling designed to provide a direct assessment of the ratios of unmarked to marked fish available during a particular mark-selective fishery. This idea has been explored by SFEC (2002) and would require the existence of paired NSF and MSF that are operating at similar times and places.

During the course of the Panel deliberations, we considered well over 100 combinations of alternative mass marks (adipose or ventral clip), indicator stock identifiers (CWT, genetic pedigree analysis, genetic stock identification, or otolith mark), and analytical methods for estimating the mortality of unmarked fish in MSFs. Characteristics of four methods and sources of more detailed information on the estimation procedures are summarized in Table 11. Our preliminary analysis of these methods indicates that no

single method will provide precise and accurate estimates of stock-specific mortality of unmarked fish in MSFs under all circumstances.

Fully defining the conditions under which alternative estimation methods should be employed will likely require the development of simulation tools to test alternative estimators under a variety of fishery, marking, survival, and sampling conditions. Although the intensity of MSFs that may be prosecuted in the future cannot be predicted with complete accuracy, the PSC's processes for obtaining information on MM and MSFs may be sufficient to identify a likely range of fisheries

Table 11. Four scenarios describing the combination of a mass mark, a uniquely marked or tagged indicator stock, and the estimator for the mortality of unmarked fish of the indicator stock in a MSF.

Scenario	Mass Mark	Indicator Stock Mark and Tag	Mortality Estimator for Unmarked Fish in MSF (Reference)
SIT with MSF mortalities estimated by fishery.	Adipose-clip	Group 1 {adipose-clip, CWT)	Method 1. Group 1 recoveries multiplied by release mortality rate (ASFEC 1992).
DIT with MSF mortalities estimated by fishery.	Adipose-clip	Group 1 {adipose-clip, CWT} Group 2 (no clip, CWT}	Method 2. Group 1 recoveries multiplied by ratio of Group 2 to Group 1 juvenile releases and release mortality rate (ASFEC 1992).
DIT with total MSF mortalities estimated across fisheries.	Adipose-clip	Group 1 {adipose-clip, CWT} Group 2 {no-clip, CWT}	Method 3. Total MSF mortality derived from differences in age-specific escapement rates (or terminal run) of Group 1 and 2 fish (Appendix A).
Enhanced DIT with Paired Fishery	Adipose-clip	Group 1 {adipose-clip, CWT} Group 2 {no clip, CWT} Group 3 {adipose-clip, otolith} Group 4 {no clip, otolith}	Method 4. Group 1 recoveries multiplied by ratio of Group 4 to Group 3 recoveries in paired fishery and release mortality rate (enhanced version of method described in SFEC (2002).

Citations.

Alexandersdottir, M., Hoffmann, A., Brown, G. and P. Goodman. 2004. Technical Review of the CWT System and Its Use for Chinook and Coho Salmon

Management. Presentation to Expert Panel, June 7-10, 2004 at Workshop on Future of the CWT Program: Challenges and Options

Hoffmann, A. and M. Alexandersdottir 2004. Impact of mass marking and mark-selective fisheries on use of CWT data for chinook and coho management. Unpublished manuscript available from the Pacific Salmon Commission, Vancouver, British Columbia, Canada.

RECOMMENDATION 8. *The PSC should explore the interest of fishery agencies in participating in a Grand Experiment to improve the basis for harvest management decisions coast-wide through an intensive program conducted over a short period of time. If interest is sufficient, the PSC should: (a) charge its Technical Committees (Chinook, Coho, and Selective Fishery Evaluation) with the task of preparing draft specifications for the Grand Experiment; (b) solicit proposals to assess the feasibility of conducting the experiment and develop a detailed experimental design, including cost estimates; (c) seek funding for implementation; and (d) coordinate conduct of the experiment.*

Background.

Current fishery regimes for chinook and coho salmon are commonly based on evaluation of projected impacts of proposed regulations on natural stocks of concern. By and large, these projections are based on management planning models that employ estimates of stock-age-fishery-specific exploitation rates estimated using data collected from CWT experiments during some historical time period (base period).

Data presently used for modeling have several deficiencies:

1. CWT release groups selected to represent natural stocks were opportunistically selected , i.e., they happened to be available and did not have properties that would make them unsuitable for modeling. As a consequence, coverage of stocks and release types is often incomplete with respect to current needs and management models;
2. Data were collected during disparate periods, often when catch sampling regimes were inconsistent and lacked full coverage throughout the migratory range of the fish;
3. Fishery regimes that are being evaluated often differ substantially from those that were observed during model base periods – e.g., WCVI smaller size limits, winter periods, hatchery directed fisheries in Alaska, Mark-Selective Fisheries, etc.;
4. Observational data for estimation of model parameters relating to natural mortality rates, age-structure of spawning escapements, and incidental fishing mortality rates were so sparse that values had to be assumed or drawn from the literature

Fishery managers are being confronted with unprecedented demands for increased success in constraining stock-specific fishery impacts to allowable levels. The diminishing capacity of current models and their underlying data to achieve these fishery impact constraints is of increasing concern.

It is expected that fishery management and assessments will continue to rely heavily upon models, both for pre-season planning and post-season evaluation. The data collected from a Grand Experiment would be essential to validate critical assumptions and would likely spur improvements in model design and performance that would enhance the ability of models to provide accurate and useful information to agencies as they decide how fishery impacts are to be constrained to meet management objectives.

For a variety of reasons, the capacity to collect data to improve the basis for management models can be expected to continue to deteriorate, so the opportunity to obtain these data in the future will likely diminish with time.

The concept of a "Grand Experiment" is not without precedent. In 1962, a large scale marking program for Columbia River chinook salmon was initiated. The study involved sequestration of fin-marks, coast-wide fishery sampling, and centralized reporting. In 1965, the experiment was expanded to include coho salmon. The improved information available through these experiments and coordination protocols became evident and eventually led to the establishment of the Mark Processing Center in Oregon in 1970.

The cost of conducting the experiment would be substantial, but the potential exists to significantly improve the basis for harvest management coast-wide. Funding sources that might be approached for financial support include the Northern and Southern Endowment Funds administered by the PSC, the Bonneville Power Administration, and federal appropriations.

Objectives for a Grand Experiment:

(1) Collect reliable data (catch, effort, regulatory history, tag recovery estimates, sampling of fisheries and escapements) to improve parameterization of fishery planning models for chinook and coho. Planning models are anticipated to continue to play critical roles in helping fishery managers determine appropriate regulatory packages to meet resource conservation and utilization objectives to individual stocks.

(2) Test the validity of critical assumptions underlying stock and fishery assessment methods (e.g., estimated non-landed mortality rates, representation of natural stock impacts by hatchery indicator stocks).

(3) Obtain additional information to improve the scientific basis for harvest management (e.g., determine if mark-types influence patterns of fishery exploitation, compare results of CWT and genetic based estimates of stock composition, assess variability in stock-distribution and fishery exploitation patterns, increase the capacity to incorporate uncertainty and risk to the ability to attain management objectives).

Elements of a Grand Experiment:

The experiment would be conducted for 3-4 broods released in successive brood years so that the total duration of the experiment would be about 8-9 years for chinook, and involve coast-wide commitments to collaborate and contribute to the intensive data collection program.

Although details of the Grand Experiment have not been fully developed, it is anticipated that the principal components of the experiment would include:

1. A coast-wide experimental design that includes:

a. Specifications for planning models and methods, including data requirements for parameterization and targets for confidence levels;
b. Selection of indicator stocks and fishery strata;
c. Determination of requisite tagging levels and specification of standards for sampling fisheries and escapements to collect CWTs[5]
d. Monitoring programs to collect information on sex-age composition of escapements, and tissues for genetic baselines
e. Experiments to obtain data necessary to estimate incidental fishing mortality rates (e.g., drop off, release, unmarked-retention error, mark recognition error, changes in encounter rates resulting from species targeting or gear restrictions)
f. Standardized methods for data analysis
g. Sampling programs to quantify encounters and collect tissue samples and scales from fish that cannot be legally retained;
h. Genetic analysis of tissue samples and scales using agreed upon methods
i. Quality assurance/control measures to ensure that complete and accurate data are collected and timely reported;

2. A set of coast-wide agreements which encompass:
   a. The development of a coastline genetic baseline for stocks at desired levels of resolution, sharing of genetic materials, and establishment of scoring and processing protocols for genetic stock identification;
   b. Support for intensive data collection programs for fisheries and spawning escapements for the duration of the experiment;
   c. Adherence to a plan and schedule to complete analyses and incorporate information into planning processes and models.

Citations.

Johnson, K.J. 2004. Regional Overview of Coded Wire Tagging of Anadromous Salmon and Steelhead in North America. Paper originally published in 1990 entitled "Regional overview of coded wire tagging of anadromous salmon and steelhead in Northwest America" in the American Fisheries Society Symposium 7:782-816. Paper was updated for the CWT Workshop convened by the Pacific Salmon Commission in June 2004.

[5] Federal & state mass marking directives provide opportunity to place large numbers of CWTs on hatchery release groups at minimal additional cost – collection of more tags, even with MSFs, would provide better estimates of stock-age-fishery specific exploitation rates than those currently employed by existing fishery planning models.

RECOMMENDATION 9. *The PSC and management agencies should initiate a coordinated research and implementation plan to assure application of improved technology in the management of salmon fisheries.*

RECOMMENDATION 10. *Additional experiments should be conducted to evaluate the use of alternative external marks (e.g., a ventral fin clip or some alternative fin clip) for identification of fish bearing CWTs. Existing published information suggests that application of other external marks (e.g., a ventral fin clip) will reduce the survival of hatchery fish from release to age 2, but there is little evidence of differences in survival or behavior of externally marked versus unmarked fish past age 2. We propose some experiments that would allow, among other things, testing of a null hypothesis that survival rates for (a) AD + CWT + alternative external mark and (b) AD + CWT fish are the same from age 2 on, i.e., that there is no lingering differential mortality due to, for example, ventral fin marking.*

Some of the problems that we have identified concerning mass marking and mark-selective fisheries can be directly traced to the decision to use the adipose fin to identify mass marked fish. This "desequestering" of the adipose fin has created the need and associated expense for electronic detection of tags and has indirectly lead to failure to collect CWT recovery data in certain areas as well as other inconsistencies in CWT recovery efforts in different areas (see Tables 2 and 3 in Part I). It would be highly desirable to find some other suitable external mark that could be used to identify mass marked fish or as an exclusive identifier of CWT fish or as an identifier of FPG fish. One obvious candidate would be the ventral fin clip.

In our review of the effects of application of ventral fin clips, we found substantial evidence that overall apparent survival rates (e.g., total recoveries over a cohort's lifespan compared to numbers released) of hatchery Chinook and coho salmon can be reduced by application of ventral fin clips, sometimes dramatically (more than 50% reduction) but sometimes only modestly (< 5%). We suspect, but have not verified, that the observed wide range of survival effects due to application of a ventral fin clip in large part reflect differences in fish size at the time of mark application or fish release size. Generally, if fish are smaller at marking and release, then effects on survival will probably be greater than if fish are larger at marking and release.

If a ventral fin clip were used as a mass mark, instead of the adipose clip, then the adipose fin clip could once again serve as a unique identifier of CWT fish. However, use of a ventral fin clip as a mass mark might result in unacceptable loss of fishing opportunities on hatchery fish due to reduced survival. If the ventral fin clip were instead used as an identifier of CWT fish, then the effect on overall survival could presumably be compensated for by increased numbers at release. If the ventral fin clip reduced survival from release to age 2 only, but did not thereafter affect ocean survival or migratory behavior of CWT fish, then the ventral clip would be an acceptable external mark from the standpoint of providing data necessary to estimate stock-age-fishery specific exploitation rates for unmarked fish.

We therefore believe that it is important to carry out some carefully structured studies in which contrasting CWT groups of Chinook salmon (of various sizes) and coho salmon juveniles are released from hatcheries, ideally from several different hatcheries selected to have rigorous freshwater sampling programs in place, with the following alternative paired fin mark and tag combinations (ventral fin clip used as an illustrative example) : Group A - adipose clip + CWT + ventral fin clip; Group B – adipose clip + CWT. The contrast in calculated survivorship to age two for the two groups would allow an assessment of the overall survival impact of the ventral fin clip (given fish have already been adipose clipped). The distributions of recoveries over ages and locations for the two groups could then be compared to see if there is continuing evidence of reduced survival or other behavior effects for fish that received the ventral fin clip. If such evidence were detected, then the ventral fin clip could not be recommended as an identifying mark for hatchery fish released with CWT because survival rates from age 2 on for ventral clipped fish would then be expected to differ from those of the associated unmarked wild stock for which inferences concerning exploitation patterns would be desired. But if no such effects were detected, then the ventral clip could be judged suitable as an external identifier of CWT fish.

Finally, we wish to emphasize that we fully recognize the potential disadvantages (primarily reduced survival rate to age 2) of applying some non-adipose fin clip to fish released as part of CWT experiments in terms of the number of marked fish available for harvest. But we believe that the mortality impacts of mark application must be weighed against the full costs of using electronic detection in ***all*** fisheries or of taking heads from ***all*** adipose clipped fish in all fisheries. CWT releases of hatchery fish are often used as surrogates for small natural stocks of concern, and the numbers of fish in such CWT releases may be relatively small (generally, no more thatn 200,000 fish). Without an identifying external mark that reliably indicates the presence of a CWT, either all fish must be scanned for presence of a CWT (electronic detection) or all heads must be collected from all fish possessing adipose clips (many or most of which may not have CWTs if mass marking is greatly expanded). MSF impose the further requirement that ***all*** unmarked fish in catches be scanned for CWT so that harvests of fish belonging to DIT groups may be estimated (assuming that DIT analysis procedures require estimates of catch of unmarked CWT fish in NSFs). If CWT fish always received an external identifying mark, distinct from the mass mark, then there would be no need for ETD or for collection of heads from all adipose-clipped fish; CWT could then be unambiguously separated from MM fish.

RECOMMENDATION 11. *We recommend that programs be developed and implemented to enhance the capacity to apply genetic methods to stock identification problems of concern to the Pacific Salmon Commission.*

GSI methods are developed to the point where there is little doubt that they are capable of providing information that would improve the basis for fishery management. Some of this information cannot be readily obtained through CWT experiments. For example, non-lethal sampling can provide estimates of the stock composition of sub-legal sized fish (not available in samples of landed catch), which can then be compared to estimates generated through the use of models and assumptions. Genetic methods can also provide direct information on catch composition and encounter rate of legal-sized fish from untagged naturally spawning stocks. When coupled with CWT data, such estimates would be helpful for testing the similarity in distributions of natural stocks and selected CWT releases of hatchery fish and for generating estimates of production expansion factors (which in turn could provide a means to estimate spawning escapements of naturally spawning fish – see Appendix C). Genetic information could also be employed for in-season management of fisheries to target stocks with large harvestable surpluses or avoid stocks of particular conservation concern, as evidenced by presentations to the Panel at the CWT Workshop.

A major potential obstacle to the coast-wide application of GSI methods is a lack of adequate collaboration and coordination among entities involved in the development and implementation of genetic methods and GSI-based stock composition estimates. It is the Panel's view that institutional barriers must be overcome and standards/protocols developed and adhered to for genetic methods to be broadly accepted for management use. The Panel recommends that the following measures be taken:

1. Establish coast-wide standardized genetic databases (see *Finding 15*) with adequate (number of samples and level of resolution) representation of populations encountered in the fisheries in which GSI is to be applied;

2. Identify minimum standards for sampling programs to provide estimates of acceptable reliability for the intended purpose (point estimates for stock composition and confidence intervals for uncertainty). Sampling rates and sizes should reflect fishery-specific considerations for the stock composition and the stocks to be targeted. For example, small sample sizes may be adequate for a stock that comprises a large proportion of the catch, but inadequate for small stocks of conservation concern;

3. Establish data analytic and accession protocols to ensure that results are replicable and that management agencies are confident with the accuracy of the results. At a minimum, this would involve: (a) continual improvement of standardized genetic databases; (b) clear documentation of the analytic procedure used to generate estimates of stock composition, including populations in the genetic "baseline" database employed, tissue processing procedures used, and specific mixture analysis models employed; (c) standardized allele calling methods for microsatellite-based analyses, (d) a functional, reciprocal system for accession of tissue samples used for database construction and in fishery samples (for a reasonable, but short, period of time); and (e)

data collection, processing, and reporting systems that satisfy requirements for timely management response.

RECOMMENDATION 12. *We recommend that the Pacific Salmon Commission support an immediate evaluation of a coordinated transition for all salmon species from genetic stock identification (GSI) based on the use of microsatellite markers to GSI based on single nucleotide polymorphism (SNPs) markers. It is important to develop standard sets of species-specific SNPs and related protocols now, so that coast-wide implementation of SNP-based GSI will be cost-effective and efficient. The best approach to such a transition is for a multi-jurisdictional agency, such as the PSC, to coordinate broad, multi-agency collaborations such as those adopted during the development of the coast-wide allozyme data bases during the last decade or during the development of the CTC standardized Chinook microsatellite data base developed over the last two years. Such collaborative efforts should include provisions for future tissue sample availability from all stocks included, so as to provide for periodic improvement and expansion of the databases.*

Microsatellite markers have been extraordinarily useful in salmonid population genetics over the last decade, as they have provided unprecedented power for stock separation in GSI. However the nature of microsatellite data, relative allele size, as well as the diversity of molecular genetic equipment in use by salmonid geneticists, makes microsatellite data impossible to replicate independently or combine between laboratories without a resource-intensive standardization process. Moreover, the initial development of sets of microsatellite markers for GSI independently in different laboratories has resulted in almost no overlap in the specific markers in use in salmon genetic labs for most species. A $1.1 million effort was necessary to standardize 13 microsatellite markers for Chinook salmon, and this includes (most of) the costs for 7 labs only.

SNP markers, in contrast, require no standardization in allele designation, as alleles represent absolute biochemical state, not relative size. SNP data can thus be independently replicated and combined with data from other laboratories with no standardization effort. In addition, SNP data has a much lower laboratory error rate and can be produced at a much lower cost. Indeed, the human genetics "community" has already undergone a transition from microsatellites to SNP markers and contract genetics laboratories produce a human single marker SNP genotype for less than $0.10.

The past transition from allozyme to microsatellite markers as a fishery genetic tool, and associated high costs, raises the question of whether a transition to SNP markers will be another costly undertaking that leads to a tool destined to be obsolete in several years. The Panel believes that this is unlikely to be the case, as SNPs are the most abundant form of genetic variation in the vertebrate genome, with a useful SNP marker present every few thousand nucleotides in large out bred populations. Moreover, SNP markers are direct assays of changes in the fundamental units of the genetic code, nucleotides, and not indirect assays, such as allozymes. Microsatellites, while also direct DNA assays, measure the relative lengths of repetitive genomic regions only and are much less abundant than SNPs. In addition, microsatellites are primarily found in non protein-coding DNA sequences, whereas SNPs are found in both coding and non-coding DNA sequences. Since particular SNPs are ultimately responsible for most heritable phenotypic variation in salmon, they are therefore probably the fundamental unit of

genetic variation from both a population genetic and biological standpoint. The prospect of markers that will not become quickly obsolete and offer the potential for additional understanding and monitoring of important biological traits, coupled with the ease of standardization, lower laboratory error rates, and the potential for greatly reduced data collection costs, have convinced the Panel that future applications of genetic methods for salmon management should employ SNP markers.

Since SNP markers are only now being developed for salmon species, it is important that a multi-jurisdictional approach to development be adopted to avoid non-overlapping sets of markers being employed in different labs. Once substantial resources have been expended for data collection with specific markers, it becomes costly for individual labs and agencies to switch to other markers. Initial adoption of the same marker sets by all labs and agencies providing genetic data for salmon management can thus save substantial resources in the long run. An agency with broad jurisdiction, such as the PSC or NPAFC, would be the best moderator of such an effort, as local agencies will tend to choose genetic markers that are most efficient for regional issues, but may not be useful coast-wide. The availability of tissue samples from all stocks included in the baseline databases for GSI is necessary to be able to best build on the existing data and to maintain geographic coverage as the databases evolve. This will benefit from the use of the same individuals whenever possible, although baseline databases and, therefore, available tissues, should be periodically updated to monitor changes in allele frequencies of marker genes.

***RECOMMENDATION 13.**. We recommend support of a "proof-of-concept" empirical validation of the Full Parental Genotyping (FPG) method for use in management of Pacific salmon fisheries. This validation should occur in Chinook salmon and should include support for further SNP development, a series of paired CWT and FPG tag recovery experiments, as well as thorough evaluation of relative costs of implementing these methods and the sampling necessary to provide equivalent tag recovery data.*

The Panel was presented with a conceptual overview of the FPG concept (see Finding 18), a more technical oral presentation, and an unpublished manuscript on this topic. Based on our review of these materials, the Panel believes that FPG can, in principle, provide stock and age of origin for individual hatchery fish for which parental broodstock have been genotyped through parentage analysis of fishery samples. Threoretically, with a relatively large (about 100), but feasible, number of SNP markers, these assignments can be made essentially without error, even under relatively conservative assumptions about error rate and other parameters. The ability to determine both age and stock of origin for all hatchery fish would allow collection of data using a genetic-based method that is identical to that from a CWT program. FPG would not provide a direct solution to the problems of MM and MSF, nor would it allow increased tagging proportions in small stocks. However, it would provide 100% marking for all hatchery fish, so the absolute number of tags, for both large and small stocks, would be greater. The easy integration of FPG with GSI also offers the prospect of fishery samples where almost every fish has a tag: GSI could provide stock of origin for non-hatchery fish, and FPG could provide cohort information for any spawner sampled at hatcheries or through interception at, for example, weir or fish ladders.

The FPG method is conceptually feasible, yet has not been validated in the field with large populations. A "proof-of-concept" study at several large hatcheries that contribute significantly to ocean harvest should evaluate the feasibility, in practice, of the FPG method.

RECOMMENDATION 14. *We recommend that a feasibility study be conducted to determine how PIT, RFID or other electronic tags might be applied to generate data suitable for full cohort reconstruction.*

A feasibility analysis should be completed to evaluate the utility of the hypothetical framework described above for electronic tags. The analysis should include the following elements:

1. A list of the advantages of the method over the existing CWT system;
2. A list of potential disadvantages compared to the existing CWT system;
3. A description of the logistical requirements for implementation;
    i. Technical requirements for coast-wide data collection
        a. What equipment and facilities are required
        b. What factors would affect the timing of implementation
        c. How should the transition from the existing CWT system be handled?
        d. How should performance be evaluated?
    ii. What sampling systems and regimes are required to collect the data?
    iii. How will data be reported?
4. Identify estimated costs of implementation.
    i. What are the costs to establish the system?
    ii. What are the likely annual and periodic costs to maintain the system?
    iii. Will the method provide any cost savings compared to current expenditures for the CWT system?
    iv. What is the life expectancy of the technology and equipment?
5. A technical analysis that contains the details of how electronic tags can provide the data required to estimate age-fishery specific estimates of exploitation rates for natural stocks. The content of the analysis should include:
    i. A description of the theory
    ii. An evaluation of likely uncertainty
        a. What are the primary sources of imprecision in the data and how do they contribute to total uncertainty in estimates of stock-age-fishery exploitation rates?
        b. What are the primary sources of bias in the data and how do they contribute to total uncertainty in estimates of stock-age-fishery specific exploitation rates?
        c. How would this uncertainty affect implementation of PSC regimes for chinook and coho?

RECOMMENDATION 15. *PSC technical committees should explore potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation (or non-landed mortality) rates, but that would still ensure adequate protection for unmarked natural stocks of concern.*

Implementation and enforcement of the PSC's current management regimes for chinook and coho salmon rely upon the capacity to estimate stock-age-fishery-specific exploitation rates from CWT data (Morishima, 2004). For many reasons that have been enumerated elsewhere in this report, it is questionable that the CWT system will be capable of producing reliable estimates of exploitation rates in the future, especially at the finer scale of fishery resolution that appears contemplated for future management regimes.

PSC regimes for chinook and coho salmon are due to expire in 2008. In light of increasing concern for conservation of natural stocks in both the United States and Canada, it will be critical for the PSC to develop future management regimes with a focus on the capabilities of data collection and management systems to provide reliable estimates of statistics necessary to evaluate performance.

The Panel questions the advisability of developing future management regimes that rely upon the ability to estimate stock-age-fishery-specific exploitation rates and recommends that PSC technical committees and panels be tasked with the responsibility to investigate alternative ways to manage chinook and coho salmon. A number of approaches could be considered; as a starting point, alternatives discussed at workshops convened by the PSC in the early 1990s and a working document prepared by the CoTC should be reviewed (CoTC, 1986). The timing of such an investigation may also be opportune from the standpoint of the spirited dialogue presently occurring in Canada in response to proposals for major restructuring of fisheries as recommended by the McRae-Pearse Report (McRae and Pearse, 2004) and others (First Nation Panel on Fisheries, 2004; Schwindt et.al., 2003; Wakter et.al., 2000)

In addition to strategies identified in prior PSC forums, our preliminary investigations indicate that we are much more likely to be able to generate reliable estimates of total non-landed mortalities at age for unmarked natural stocks than stock-age-fishery- specific estimates of exploitation rates. Estimates of total non-landed mortalities at age can, when combined with estimated landed mortalities at age, provide estimates of total fishery-related mortality at age. When coupled with data from monitoring programs on spawning escapement levels and production responses, this kind of information should be sufficient to judge whether or not natural stocks are being impacted by fisheries at a sustainable or unsustainable level. The management challenge would then turn to two areas: (1) allocation of allowable impacts; and (2) development of practical and effective measures that could be employed in fishery regulation to constrain fishery impacts to allowable levels and monitor impacts. Allocation is a matter of negotiation to find acceptable political accommodation. The ability of management measures to meet stock-specific objectives will involve both technical feasibility and assessment of costs and benefits.

The Panel was also presented with an example of achieving stock-specific constraints through use of inseason sampling and genetic methods to limit encounters of a small set of stocks (Beacham and Withler, 2004). It is unclear how such a system might perform when attempting to provide a means of constraining harvest impacts on a large number of stocks. Such a system would have several undesirable consequences, such as reducing the predictability of fishery openings and closures and increasing the difficulty of negotiating and developing fishing plans, but might improve the total allowable harvest from populations that have healthy status and are less sensitive than natural stocks of concern.

Citations.

Beacham, T. and R. Withler. 2004. Application of genetic-based methods in the management of chinook and coho. June 9, 2004 presentation by Terry Beacham and Ruth Withler.

Coho Technical Committee. 1986. "Alternative Management Strategies for Coho." PSC 1991. " A Report to the Pacific Salmon Commission on a Workshop Held at Vancouver, B.C. January 10 and 11, 1991 To Explore Alternative Chinook Management Approaches" PSC. 1992. "Report to the Pacific Salmon Commission on the Southern Area Coho Workshop". Dunsmuir Lodge, Victoria, B.C., February 17-18, 1992.

McRae, D.M. and P.H. Pearse. 2004. Treaties and Transition: Towards a Sustainable Fishery in Canada's Pacific Coast. April 2004. First Nation Panel on Fisheries. 2004. Our Place at the Table: First Nations in the B.C. Fishery. May 2004. Schwindt, R., A.R. Vining, and D. Weimer. 2003. A Policy Analysis of the B.C. Salmon Fishery. Canadian Public Policy vol XXIX 1 2003:73-94. Wakter, E., R.M. M'Gonlgle, and C. McKay. 2000. Fishing Around the Law: The Pacific Salmon Management System as a "Structural Infringement" on Aboriginal Rights. McGill Law Journal (45):263-314.

First Nation Panel on Fisheries. 2004. Our Place at the Table: First Nations in the B.C. Fishery. May 2004.

Morishima, G. 2004. In a nutshell: coded wire tags and the Pacific Salmon Commission's fishery regimes for chinook and southern coho salmon. Paper prepared for the CWT Panel. Pacific Salmon Commission.

Schwindt, R., A.R. Vining, and D. Weimer. 2003. A Policy Analysis of the B.C. Salmon Fishery. Canadian Public Policy vol XXIX 1 2003:73-94.

Wakter, E., R.M., M'Gonlgle, and C. McKay. 2000. Fishing Around the Law: The Pacific Salmon Management System as a "Structural Infringement" on Aboriginal Rights. McGill Law Journal (45):263-314.

PART IV. APPENDICES

APPENDIX A. Proposed Scheme for Estimation of Total Age-Specific Non-Catch Mortalities to Unmarked Chinook Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries.

APPENDIX A. Proposed Scheme for Estimation of Total Age-Specific Non-Catch Mortalities to Unmarked Chinook Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries[1]

CONTEXT

Assume the use of *double index tagging* (*DIT*) tagging methods. By this method, two groups of hatchery fish are reared and released identically and in a fashion designed to allow inference of fishery impacts and life history attributes (age-specific maturation probabilities) for unmarked natural stocks for which the tagged groups serve as surrogates. The groups differ only in application of an adipose fin clip. One group is adipose fin-clipped and coded wire tagged with coded wire tag number M. A second group of fish is coded wire tagged with code wire tag number U, but is not adipose fin-clipped.

Assume that the two release groups are subjected to ocean and freshwater fisheries and that ocean fisheries are of two types: non-selective fisheries in which all legal-sized fish (marked and unmarked) may be retained, and mark-selective fisheries in which only marked fish (i.e., adipose-clipped) may be retained. Interest lies in estimation of the total age-specific non-catch mortalities in selective ocean fisheries for the unmarked group which cannot be estimated via direct sampling protocols. Ideally, the PSC would also wish to estimate age- and fishery-specific non-catch mortality rates for unmarked fish in individual mark-selective fisheries but, as the development below suggests, it may not be possible to generate essentially unbiased estimates of non-catch mortalities at that fine scale of resolution.

Assume that adequate CWT recovery programs are in place so that a complete (marked group) or nearly complete (unmarked group) age-structured statistical accounting of the fate of the two release groups can be accomplished. To accomplish such an accounting, I assume that recovery programs generate approximately unbiased estimates of age-specific ocean catch for adipose-clipped fish in both non-selective and mark-selective fisheries, and of age-specific spawning escapement (freshwater catches + hatchery returns + stray (non-hatchery) escapement). I further assume that approximately unbiased age-specific estimates of ocean catch in non-selective ocean fisheries, and spawning escapements are available for the unmarked group. Typically, the most problematic element of such an accounting is generation of an approximately unbiased estimate of stray escapement for hatchery release groups. Generation of an estimate of stray escapement requires implementation of a rigorous program for estimation of total escapement as well as carcass survey programs designed to allow estimation of the proportion of hatchery fish (with a given CWT number) present in natural spawning areas. [2]

Given the marking and release protocols specified above and the existence of rigorous CWT recovery programs that can generate approximately unbiased estimates of ocean and freshwater fishery catches and spawning escapements, it appears that essentially unbiased [3] estimates of total

[1] David G. Hankin, Department of Fisheries, Humboldt State University, Arcata, CA 95521,03 January 2005

[2] Note that to improve accuracy of estimation of stray escapement and ocean catches for the *unmarked* group, I propose that we consider adding an auxiliary mark (e.g., ventral fin clip) to both release groups so that there is no need for electronic detection in ocean or freshwater catches, in spawning escapement surveys, or at hatcheries.

[3] The estimators presented in this paper are all effectively "moment-type" estimators which generally have small statistical bias. As such, they are not strictly unbiased, but they are distinguished importantly from estimation methods that invoke assumed values of, for example, non-catch mortality rates or ratios of unmarked to unmarked fish at time of fisheries, when the assumed values have unknown and possibly substantial bias and are completely independent of generated CWT recovery data. The estimators are all only *conditionally* unbiased because they require that ocean natural survival rates are known (see section on estimator development). Estimates of non-catch mortalities will therefore have bias resulting from the degree that assumed natural survival rates differ from the true

age-specific non-catch mortalities can be calculated using the DIT approach.

DEFINITIONS:

i = age = 2, 3, 4, 5(and also age 6 for late-maturing stocks)

$N_{i,M}$ = Ocean abundance of CWT $\#M$ at age i, immediately prior to fishing season

$N_{i,U}$ = Ocean abundance of CWT $\#U$ at age i, immediately prior to fishing season

$C_{i,M,ns} = \sum_{f_{ns}=1}^{ns}$ Ocean catch of CWT $\#M$ in non-selective ocean fisheries at age i

$C_{i,U,ns} = \sum_{f_{ns}=1}^{ns}$ Ocean catch of CWT $\#U$ in non-selective ocean fisheries at age i

$C_{i,M,s} = \sum_{f_s=1}^{s}$ Ocean catch of CWT $\#M$ in mark-selective ocean fisheries at age i

$I_{i,U,s} = \sum_{f_s=1}^{s}$ Non-catch mortalities to CWT $\#U$ in mark-selective ocean fisheries at age i

$E_{i,M}$ = Freshwater escapement of CWT $\#M$ at age i

$E_{i,U}$ = Freshwater escapement of CWT $\#U$ at age i

$S_{0,M}$ = Survival from release to ocean abundance at age 2 for CWT $\#M$

$S_{0,U}$ = Survival from release to ocean abundance at age 2 for CWT $\#U$

$\sigma_{i,M}$ = Age-specific maturation probability for CWT $\#M$ at age i

$\sigma_{i,U}$ = Age-specific maturation probability for CWT $\#U$ at age i

S_i = Conditional ocean survival rate from age i to $i+1$

Y_M = Number released for CWT $\#M$

Y_U = Number released for CWT $\#U$

ESTIMATOR DEVELOPMENT

In the development that follows below, Y_M and Y_U are known, and I have assumed that unbiased estimates are available for $C_{i,M,ns}$, $C_{i,U,ns}$, $C_{i,M,s}$, $E_{i,M}$, and $E_{i,U}$. We desire (approximately) unbiased estimators of age-specific non-catch mortalities to the unmarked CWT group $\#U$, $I_{i,U,s}$.

Case 1. No natural mortality during fishing season.

Assumed Sequence of Events:

For this case[4], assume a *Type 2* fishery with the following sequence of events:

natural survival rates experienced by CWT release groups

[4]Note that the Case 1 scenario is most appropriate for a fall Chinook salmon stock subject to spring/summer (say, April-September) fisheries which are intensive so that it is reasonable to assume that natural mortality is negligible compared to fishing mortality over the course of the fishing season.

1. The initial abundances at age i, $N_{i,M}$ and $N_{i,U}$, are subjected to a mixture of non-selective and mark-selective fisheries generating catches that may be directly estimated ($C_{i,M,ns}$, $C_{i,U,ns}$, $C_{i,M,s}$) and unobservable non-catch mortalities in selective fisheries for group #U ($I_{i,U,s}$)

2. Maturation at age is assumed to take place immediately following ocean fisheries, thus leading to age-specific escapements for the groups $\#M$ and $\#U$ ($E_{i,M}$, $E_{i,U}$)

3. Given that an age i fish has not been caught or suffered non-catch mortality in ocean fisheries and has not matured at age i, ocean natural mortality (via S_i) is assumed to take place immediately following maturation and covers the period from maturation of fish until subsequent availability in the following year's fishery at age $i + 1$.

Cohort Analysis for Adipose-Clipped Group (CWT $\#M$):

Cohort reconstruction methods applied to single release groups require that either age-specific maturation probabilities or age-specific natural survival rates (S_i) are known. I assume that the S_i are known and have the following values: $S_2 = 0.50$, $S_3 = S_4 = 0.80$. For a single cohort, reconstructed abundances at age 2-5 are:

$$\begin{aligned}
\hat{N}_{5,M} &= \hat{C}_{5,M,ns} + \hat{C}_{5,M,s} + \hat{E}_{5,M} \\
\hat{N}_{4,M} &= (\hat{N}_{5,M}/0.80) + \hat{C}_{4,M,ns} + \hat{C}_{4,M,s} + \hat{E}_{4,M} \\
\hat{N}_{3,M} &= (\hat{N}_{4,M}/0.80) + \hat{C}_{3,M,ns} + \hat{C}_{3,M,s} + \hat{E}_{3,M} \\
\hat{N}_{2,M} &= (\hat{N}_{3,M}/0.50) + \hat{C}_{2,M,ns} + \hat{C}_{2,M,s} + \hat{E}_{2,M}
\end{aligned}$$

Given the reconstructed estimate of ocean abundance of the marked group at age 2, one can easily calculate estimates of age-specific maturation probabilities and survival from release to age 2:

$$\begin{aligned}
\hat{S}_{0,M} &= \hat{N}_{2,M}/Y_M \\
\hat{\sigma}_{i,M} &= \hat{E}_{i,M}/(\hat{N}_{i,M} - \hat{C}_{i,M,ns} - \hat{C}_{i,M,s})
\end{aligned}$$

Estimation of Age-Specific Non-Catch Ocean Mortalities for the Unmarked Group (CWT $\#U$):

To generate approximately unbiased estimates of age-specific non-catch mortalities for the unmarked group, I invoke two reasonable assumptions. First, I assume that the survival rate from release to age 2 for the unmarked group is the same as that for the marked group. Second, I assume that age-specific maturation probabilities are the same for the marked and unmarked groups. Third, I assume that mortality to age 2 sublegal fish can be ignored. Together, these assumptions allow one to generate approximately unbiased estimates of total age-specific non-catch mortalities experienced

by legal-sized unmarked fish subject to one or more mark-selective fisheries.[5]

Invoking the assumption that survival rates to age 2 are the same for marked and unmarked groups allows estimation of the number of survivors to age 2 for the unmarked group. Namely:

$$\hat{N}_{2,U} = Y_U \hat{S}_{0,M}$$

An estimate of total non-catch mortalities at age 2 can be made by solution of an obvious expression for age 2 escapement of the unmarked group:

$$E_{2,U} = \sigma_{2,U} \left[N_{2,U} - C_{2,U,ns} - I_{2,U,s} \right]$$

Involking the assumption that $\sigma_{2,M} = \sigma_{2,U}$ and substituting estimated quantitites for true values gives:

$$\hat{I}_{2,U,s} = \hat{N}_{2,U} - \hat{C}_{2,U,ns} - \hat{E}_{2,U}/\hat{\sigma}_{2,M} \tag{1}$$

At age 3, a similar equation can be used to solve for non-catch mortalities:

$$\hat{I}_{3,U,s} = \hat{N}_{3,U} - \hat{C}_{3,U,ns} - \hat{E}_{3,U}/\hat{\sigma}_{3,M}, \tag{2}$$

where:

$$\hat{N}_{3,U} = \left[\hat{N}_{2,U} - \hat{C}_{2,U,ns} - \hat{I}_{2,U,s} - \hat{E}_{2,U} \right] S_2 \tag{3}$$

Analogous expressions allow estimation of total non-catch mortalities to the unmarked groups at ages 4 and 5. For $i = 4, 5$:

$$\hat{I}_{i,U,s} = \hat{N}_{i,U} - \hat{C}_{i,U,ns} - \hat{E}_{i,U}/\hat{\sigma}_{i,M}, \tag{4}$$

where:

$$\hat{N}_{i,U} = \left[N_{i-1,U} - \hat{C}_{i-1,U,ns} - \hat{I}_{i-1,U,s} - E_{i-1,U} \right] S_{i-1} \tag{5}$$

DISCUSSION

The estimation ideas presented above have some desirable features that seem to distinguish them from methods that have been proposed to the Expert Panel thus far. Although the proposed methods do require that one invoke an assumption that age-specific ocean natural survival rates are known, no other key parameter values are set from data external to the CWT recovery data generated by the paired marked and unmarked release groups. Other assumptions that are made, namely that survival from release to age 2 and age-specific maturation probabilities are shared by the two groups, seem unobjectionable and fully consistent with the design of the two group release

[5] In reality, for many stocks most age 2 salmon are below legal size limits at age two and it may be impossible to calculate the age 2 non-catch mortality suffered by such sub-legal sized fish. Fishermen probably try hard to avoid such small age 2 fish as they consume bait and time but return nothing to the fisherman. But if this age 2 sublegal mortality is substantial, then inability to estimate it and to incoprorate it into cohort reconstructions will lead to bias in the estimators developed in this paper.

experiment. Therefore, conditioned on the correctness of the assumed values of ocean natural survival rates, the proposed estimators should be approximately unbiased.

In contrast, the methods for estimation of non-catch mortality rates to unmarked fish that have thus far been presented to the Expert Panel have shared the required assumption of natural survival rates, but have also relied upon introduction of anciliary values or assumptions that are either known to be false (e.g., ratios of marked and unmarked groups at times of fisheries) and/or are based on information external to the CWT recovery data themselves (e.g., specification of a non-catch mortality rate). Such calculations give rise to unknown biases and I believe that they may give rise to calculated values of non-catch mortalities that are seriously at odds with the CWT recovery data themselves (e.g., if an assumed non-catch mortality rate were set much higher than the true value.)

Improved estimators based on the above logic could no doubt be constructed using methods that more directly link the recovery data for the two CWT groups. In the simple approach presented above, estimated maturation probabilities and survival to age 2 for the marked (adipose-clipped) group are imposed upon the recovery data for the unmarked group. Alternatively, one might make simultaneous use of recovery data from both CWT groups, finding estimates of survival to age 2, age-specific maturation probabilities, and age-specific non-catch mortalities for the unmarked group that make the CWT recovery from both groups most compatible with one another given iteratively calculated values for non-catch mortality impacts. The methods proposed above might be used to generate initial guesses for this kind of procedure. Presumably, resulting estimates would be better behaved than those estimators proposed above. Finally, as Ken Newman has noted, in the long term it would be desirable to cast all of the salmon cohort analysis procedures into the new state space framework where distinct sets of equations are used to describe the natural stochastic process relations among state variables and to describe the stochastic processes that generate estimates of state variable values.

The estimating equations presented above also have several undesirable features, however. First, in no case can one guarantee that the estimates of total non-catch mortalities are positive. An even more serious objection is that the estimators will fail at any age for which estimated freshwater escapement equals zero. The probabilioty of estimator failure may be large at age 2 for stocks that have a late age at maturity or when survival rates are poor and CWT release groups sizes are small[6], and may also be non-trivial for the oldest age at maturity. From a practical standpoint, this means that the above estimation methods might be applied with comfidence only for estimation of non-catch mortalities of unmarked CWT release groups at ages 3 and 4 (and possibly age 5 for a late-maturing stock).

Even when there is a non-zero positive estimate of age 2 escapement, the estimator of total non-catch mortalities at age 2 may be highly inaccurate because estimates of age 2 maturation probabilities may often be poor. Estimates of age-specific maturation probabilities at older ages are likely to be much more accurate as they are often based on larger estimated escapements and catches and because they tend generally to be larger in value (say, 0.2-0.7 across stocks). Estimates of age 2 maturation probabilities generally range from 0-0.10; therefore, small errors in estimation of σ_2 can lead to large errors in estimation of $I_{2,U,s}$ due to the errors in scaling up E_2 by $\hat{\sigma}_2$.

Finally, although the above methods may deliver essentially unbiased estimates of total non-catch mortality at age, there does not appear to be any clear recipe for allocating these total catches among 2 or more selective fisheries that may together make up the total selective fishery regime to

[6]The possibility of estimator failure and its relation to CWT release group size emphasizes the importance of reexamination of general guidelines for CWT release group size in the new context of special focus on fishery impacts on unmarked natural stocks.

which an unmarked group is exposed. A naive calculation might be to allocate non-catch mortalities according to the relative caches of the marked group across the same selective fisheries. This calculation would not be unbiased, however, because the catches of marked fish in the selective fisheries would change the abundance of the marked fish at a rate that differs from the rate of change of the unmarked fish that are subject only to non-catch mortalities in the selective fisheries. Simple numerical examples can illustrate this point.

Case 2. Natural mortality operates during fishing season.

The desirable estimation properties identified above appear to be lost if one insists on incorporating natural mortality over the course of the fishing season. To simplify presentation of the issues that are raised in this context, I consider only the fate of age 2 fish. I use a monthly time-step over the course of a four month long fishing season, and I assume that escapement takes place immediately following the fishing season. During each month, I assume that natural mortality takes place *immediately after* fishing in that month. The natural survival rate,S, in each month is assumed to be $S_i^{1/12}$, or $0.5^{1/12} = 0.94387$ at age 2 (0.98158 at ages 3, 4 and 5).

Let $N_{2,i}$ denote the age 2 abundance of the unmarked group at the end of month i ($i = 1, 2, 3, 4$), let $C_{2,i,ns}$ denote the catch of unmarked fish in non-selective fisheries during month i, and let I_2, i, s denote the non-catch mortalities to age 2 unmarked fish in all mark-selective fisheries in month i, let S ($= 0.94387$) denote the monthly survival rate, and let E_2 denote the age 2 escapement. The cohort representation for this four month fishery period would be:

$$\begin{aligned} N_{2,1} &= (N_{2,0} - C_{2,1,ns} - I_{2,1,s})S \\ N_{2,2} &= (N_{2,1} - C_{2,2,ns} - I_{2,2,s})S \\ N_{2,3} &= (N_{2,2} - C_{2,3,ns} - I_{2,3,s})S \\ N_{2,4} &= (N_{2,3} - C_{2,4,ns} - I_{2,4,s})S \end{aligned}$$

Reexpression of $N_{2,4}$ in terms of catches, non-catch mortalities, and survival rates through the four month fishing season gives:

$$N_{2,4} = N_{2,0}S^4 - C_{1,ns}S^4 - C_{2,ns}S^3 - C_{3,ns}S^2 - C_{4,ns}S - [I_{1,s}S^4 + I_{2,s}S^3 + I_{3,s}S^2 + I_{1,s}S]$$

Rearranging the above expression gives:

$$I_{1,s}S^4 + I_{2,s}S^3 + I_{3,s}S^2 + I_{1,s}S = N_{2,0}S^4 - C_{1,ns}S^4 - C_{2,ns}S^3 - C_{3,ns}S^2 - C_{4,ns}S - N_{2,4}$$

Of the terms on the right, the assumed value of S and the estimated catches in non-selective fisheries account for all of the terms involving catches, and an estimate of E_2 is assumed available. The initial ocean abundance at age 2, $N_{2,0}$, would be calculated from the cohort reconstruction of the marked group (as $\hat{N}_{2,0} = \hat{S}_0 Y_M$). If escapement of fish takes place immediately after natural mortality after the fourth fishery month, then $E_2 = \sigma_2 N_{2,4}$, so that $N_{2,4}$ could be estimated as $\hat{N}_{2,4} = \hat{E}_2/\hat{\sigma}_2$, where $\hat{\sigma}_2$ is also estimated from the cohort reconstruction of the marked group.

For case 1, S is assumed to have a value of 1.0 during the fishing season and so the left hand side would simply give the sum of the non-catch mortalities in all four months of fishing. For case 2, however, the left side is a weighted sum of the month-specific non-catch mortalities. Although the total of this weighted sum can be estimated, there is no unique solution for the month-specific non-catch mortalities and there is therefore no unique estimate of the total non-catch mortalities over the fishing season.

At ages 3 and older, the above expression may be approximately solved in a very rough fashion. At ages 3, 4 and 5, the left hand side of the expression would be:

$$0.928I_{1,s} + 0.946I_{2,s} + 0.963I_{3,s} + 0.982I_{4,s} \approx 0.955\sum_{j=1}^{4} I_{j,ns})$$

Because the weighting for the month-specific impacts are all close to 1, the simple average of the month-specific weightings (here $= 0.955$) would be not too far off from any one of the true weightings and would allow a rough algebraic solution for the total non-catch mortalities over the entire fishing season.

Estimating Non-Catch (catch-and-release) Mortalities in Individual Mark-Selective Fisheries[7]

0.0.1 Equal "encounter" rates

It may be possible to estimate the individual age-specific non-catch mortalities if you are willing to assume

a that the same "Encounter rates" are applied to the marked and unmarked group, say a 10% encounter rate applies to all fish alive at the time of a particular fishery at a particular age. This same assumption is made for both the selective and non-selective fisheries. All fish (both marked and unmarked) captured in the non-selective fishery are kept. All marked fish captured in the mark-selective fishery are kept. All unmarked fish captured in the mark-selective fishery are released, but some of these released fish die and should be counted as non-catch mortalities(see next assumption).

b the non-catch (incidental) mortality rate is the SAME for all MSF fisheries for a particular age, i.e. the same fraction of fish die after release in a MSF at a particular age. For example, it may possible to assume a constant non-catch catch-and-release mortality of xx%. Let this mortality rate be denoted by λ_a which may vary by age a.

This may be a reasonable assumption if the mark-selective fisheries consist only of, say, recreational anglers. It would be less likely to be true if the mark-selective fisheries were mixtures of recreational anglers and commercial fishermen using different gear types (e.g., nets vs troll gear). (The case where non-catch mortality rates are NOT the same in all MSF is discussed briefly in the discussion.)

As previously assumed in this Appendix, we assume that a paired DIT group has been released. The *Marked* group has CWT and an adipose-fin clip. The *Unmarked* group has CWT, but no adipose-fin clip.

Using the same notation as used previously in this Appendix, proceed as follows:

a Do a cohort reconstruction of the marked cohort.

b The encounter rates (F) for the fisheries for marked fish are computed as below (assuming for simplicity that there are 2 mark-selective fisheries denoted by $s1$ and $s2$).

$$\hat{F}_{a,M,ns} = \frac{\hat{C}_{a,M,ns}}{\hat{N}_{a.M}}$$

$$\hat{F}_{a,M,s1} = \frac{\hat{C}_{a,M,s1}}{\hat{N}_{a.M}}$$

$$\hat{F}_{a,M,s2} = \frac{\hat{C}_{a,M,s2}}{\hat{N}_{a.M}}$$

These values are equivalent to the realized exploitation rates (fraction of fish present at the beginning of the fishing season or fishing period that are captured in a particular fishery) on marked fish in both non-selective and selective fisheries, and we assume that the overall exploitation rate for unmarked fish is identical to that of marked fish in the non-selective fishery. In the selective fishery, however, all unmarked fish must be released and so we assume that

[7] Carl Schwarz, Statistics and Actuarial Science, Simon Fraser University, Burnaby, BC, Canada V5A 1S6

the unmarked fish "encounter rate" is the same as the exploitation rate for the marked fish.[8]

c Now consider the unmarked group. The total number of unmarked fish that must be alive at a given age can be estimated from the unmarked fish recovered in all non-selective fisheries, inflated by the encounter (=exploitation) rate based on the marked group:

$$\hat{N}_{a,U} = \frac{\hat{C}_{a,U,NS}}{\hat{F}_{a,M,NS}}$$

d Now consider two consecutive ages of the unmarked group. The population size at age $a+1$ is the population size at age a, less the catch in the non-selective fishery, less the incidental mortality in the mark-selective fisheries, less escapement all times the survival rate to the next age class.

$$N_{a+1,U} = \left(N_{a,U} - C_{a,U,NS} - C_{a,U,s1}\lambda_a - C_{a,U,s2}\lambda_a - E_{a,U}\right) S_a$$

A terminal fishery at age a could be included in either the non-selective fishery or in the escapement term.

e Substitute (b) into (d) because we are assuming that the same encounter rate applies to both marked and unmarked fish to get

$$\hat{N}_{a+1,U} = \left(\hat{N}_{a,U} - \hat{F}_{a,M,NS}\hat{N}_{a,U} - \hat{F}_{a,M,S1}\hat{N}_{a,U}\lambda_a - \hat{F}_{a,U,S2}\hat{N}_{a,U}\lambda_a - E_{a,U}\right) S_a$$

which can be solved for

$$\frac{\hat{N}_{a+1,U} - S_a\hat{N}_{a,U} + S_a\hat{F}_{a,M,NS}\hat{N}_{a,U} + S_aE_{a,U}}{-S_a\hat{F}_{a,M,S1}\hat{N}_{a,U} - S_a\hat{F}_{a,U,S2}\hat{N}_{a,U}} = \hat{\lambda}_a$$

f Finally, apply the estimated non-catch mortality rate to the encounter rate and the estimated abundance at age to estimate the total non-catch mortalities

$\hat{I}_{a,U,S1} = \hat{N}_{a,U}\hat{F}_{a,M,s1}\hat{\lambda}_a$

$\hat{I}_{a,U,S2} = \hat{N}_{a,U}\hat{F}_{a,M,s2}\hat{\lambda}_a$

As for the earlier method presented for estimation of total non-catch mortalities at age, this method may be unstable with small numbers of recoveries, again reinforcing the need for adequate sample sizes in all stages of the program.

0.0.2 Unequal non-catch mortality rates

The assumption of equal non-catch mortality rates may not tenable for some cohorts. For example, there is evidence that release mortality may vary with gear type, conduct of fishery, or even within a single fishery type such as recreational.

[8] Note that the assumption that marked and unmarked fish experience the same encounter rates in mark selective fisheries is not strictly correct, although it may be reasonably valid when the overall non-catch mortality rate is low and when non-catch mortalities are small compared to the total mortalities. A numerical illustration of this fact is provided in Appendix H.

It would not be possible then to separate out differential hooking mortality rates based on data from a single cohort. However, if you have multiple cohorts (each with a DIT release experiment) that are selectively fished simultaneously at different rates, then a system of n equations in n unknowns arises that could be solved for the individual non-catch mortality rates.

For example, suppose there are two selective fisheries with different incidental mortality rates, $\lambda_{a,s1}$ and $\lambda_{a,s2}$. Using the methods of Hankin, the number of each cohort alive and subject to this fishery ($N_{a,1}$ and$N_{a,2}$ and the fishing rates for these selective fisheries for each cohort ($F_{a,M1,s1}$, $F_{a,M1,s2}$, $F_{a,M2,s1}$ and $F_{a,M2,s2}$ can be estimated.

Now the total incidental mortality for each group can be estimated using Hankin's method above and must equal the sum of the catch rate in each fishery times the corresponding incidental mortality rate

$$I_{a,U1} = N_{a,1}F_{a,M1,s1}\lambda_{a,s1} + N_{a,1}F_{a,M1,s2}\lambda_{a,s2}$$
$$I_{a,U2} = N_{a,2}F_{a,M2,s1}\lambda_{a,s1} + N_{a,2}F_{a,M2,s2}\lambda_{a,s2}$$

The precision of the estimates will likely depend upon the contrast between the two cohorts. For example, if the two cohorts has exactly the same fishing rates in both selective fisheries, the system of equation is singular with an infinite number of solutions.Similarly, if there are 3 selective fisheries, you would need 3 cohorts subject to the selective fisheries to get three equations in 3 unknowns. Each cohort would be a DIT experiment.

0.0.3 Sub-stock selective fisheries

With substocks, parts of a cohort are distributed differently and subjected to different fishing and migration patterns. With CWT recoveries and cohort analysis methods, data from all substocks are ultimately pooled. Without knowing the fishing patterns of the individual substocks, the SFEC has not been able to devise a method to allocate mortalities among multiple MSFs.

If the sub-stocks could be identified in advance, the problem reduces to the ones considered above except that instead of a single cohort, there are now two (or more) distinct cohorts. A DIT experiment would need to be performed for each sub-stock.

In some cases, the distribution of fish to different areas is often environmentally driven (for example, the portion of Georgia Strait cohort that remains inside Vancouver Island is believed to be influenced by salinity). It is not presently possible to identify which fish may go where so separate tag groups for each substock are not feasible. The SFEC tried to develop the paired ratio method to try to find a way to estimate mortalities for MSFs in the presence of substocks, but finding suitable fishery pairs has been problematic in practice.

Even in cases where sub-stocks cannot be identified in advance, the methods in the previous sections may be feasible if interest lies in the pooled cohort. It does not seem possible to use the CWT system when the number of CWT releases in each sub-stock are not be known.

APPENDIX B. Can Mark-Selective Fishery Mortality Rates be Estimated from DIT Studies when Movement and/or Segregation occurs? Partial Estimates from DIT Studies.

The simplified models presented in Appendix A show that some parameters can be estimated from DIT experiments under (strong) assumptions. In this section, we consider a movement model based on that for chinook and determine what simplifications may be necessary in order to estimate the parameters of the model. The basic building block for this model is the schematic shown in Figure B1.

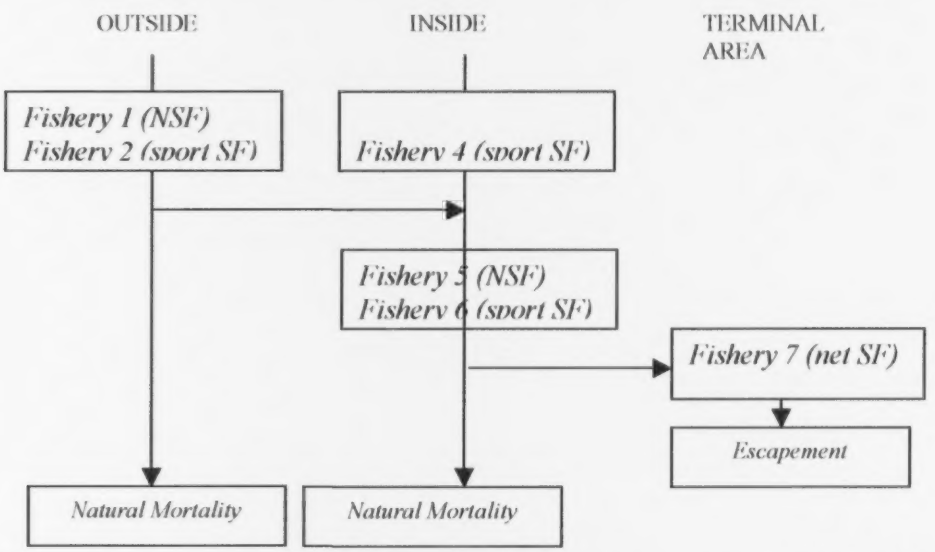


Figure B1. Schematic of simple migration model for chinook. Adopted from SFEC (2002). The schematic had a Fishery 3 that was non-selective for inside fish, but this was subsequently dropped from the models presented in the paper. Rather than renumbering all fisheries 4 to 7, the original numbering is retained.

An initial number of marked and unmarked fish are present at the start of age 2 in areas defined as outside and inside, e.g., in the ocean outside and inside the Puget Sound and Strait of Georgia. Fish that are outside are subject to a nonselective and mark-selective fishery (Fishery 1 and 2). A portion that survives the fishery, migrates inside to join the inside fish that have been subject to a selective fishery (Fishery 4). The combined group on the inside is then subject to a selective and non-selective fishery (Fishery 5 and 6). Following these fisheries, a portion of the combined group returns to the terminal area where they are subject to a selective fishery (Fishery 7) and finally some return to spawn (Escapement). The outside fish that survive the two fisheries and don't migrate inside,

survive to the next year as do the inside fish that survive the fishery and don't return to spawn. The cycle repeats at age 3 and at age 4. At age 5, all outside fish move inside after the two fisheries, and all fish return to spawn.

There are 10 "data points" that can be collected from each age class. These are (M and U refer to the number of marked and unmarked CWT fish):

- M and U from fishery 1
- M from fishery 2
- M from fishery 4
- M and U from fishery 5
- M from fishery 6
- M from fishery 7
- M and U from the final escapement.

The parameters of the model for the age 2 fish are:

- the total number of marked and unmarked fish alive at the start of age 2 (2 parameter)
- the fraction of marked and unmarked fish initial outside or inside (1 parameter)
- the exploitation rate of fishery 1 (1 parameter)
- the exploitation rate of fishery 2 and the incidental mortality rate for unmarked fish caught and released (2 parameters)
- the fraction of fish that move from outside to inside (1 parameter)
- the exploitation rate of fishery 4 and the incidental mortality rate for unmarked fish (2 parameters)
- the exploitation rate of fishery 5 (1 parameter)
- the exploitation rate of fishery 6 and the incidental mortality rate for unmarked fish caught and released (2 parameters)
- the fraction of fish that return to spawn (1 parameter)
- the exploitation rate of fishery 7 and the incidental mortality rate for unmarked fish caught and released (2 parameters)
- the natural mortality between age 2 and 3 (1 parameter).

There is a similar set of parameters for age 3 and 4 fish (except that the total number of fish and the fraction inside and outside) does not appear. At age 5, the movement from inside to outside is assumed to be 100% as is the fraction of fish that return to spawn.

The total number of parameters can be summarized as follows:

Parameters for	**# of parameters**	**Description**
At start of experiment.	3	Number of U and M fish and inside/outside split. Presumable the initial number of U and M fish could be replaced by the known number of U and M smolt released x one (common) parameter for the survival rate from smolt to age 2.
Age class 2	6	fishing rates for fishery 1, 2, 4, 5, 6, 7
	4 1 1 1	Incidental mortality rates for fishery 2, 4, 6, 7. outside-> inside movement proportion proportion of inside fish that return to spawn survival rate from age 2 to age 3
Age class 3	6	fishing rates for fishery 1, 2, 4, 5, 6, 7
	4 1 1 1	Incidental mortality rates for fishery 2, 4, 6, 7. outside-> inside movement proportion proportion of inside fish that return to spawn survival rate from age 2 to age 3
Age class 4	6	fishing rates for fishery 1, 2, 4, 5, 6, 7
	4 1 1 1	Incidental mortality rates for fishery 2, 4, 6, 7. outside-> inside movement proportion proportion of inside fish that return to spawn survival rate from age 2 to age 3
Age class 5	6	fishing rates for fishery 1, 2, 4, 5, 6, 7
	4 0 0	Incidental mortality rates for fishery 2, 4, 6, 7. outside-> inside movement assumed to be 100% proportion of inside fish that return to spawn assumed to be 100%
Total	52	

The model is clearly over-parameterized relative to the number of data points available (10/year x 4 age classes = 40). Simpler models may be able to be fit. The only sets of parameters that may be amenable to simplification are the selective fishing incidental mortalities.

For example, if the incidental mortality rate for Fishery 2, 4 and 6 were assumed equal within age classes and across age classes, the set of 12 parameters would be reduced to 1 which would give 41 parameters to be estimated from 40 data points. If the incidental mortality rate for Fishery 7 also assumed equal for all age classes, the set of 4 parameters would be reduced to 1. Both sets of simplifications would lead to models where 40 data points are available to estimate 38 parameters. This simplified model may be estimable (assuming that there is no confounding taking place among the parameters).

In the absence of being to able to simplify the model, it may be possible to obtain estimates if certain parameters are assumed constant over time and multiple (DIT) cohorts are analyzed together. Again, the incidental selective fishing mortality rates are the only parameters that may be constant over time, e.g. the selective fishery incidental mortality rate for Fishery 2 at age class 2 may be constant over time. If this assumption is tenable, then each new (DIT) cohort brings 40 data points to the table, but the number of new parameters is reduced to 36=52-16 as the 16 selective fishery incidental rates are assumed to be equal across cohorts. Eventually, the total number of data points will exceed the number of parameters, but at least 4 cohorts will be needed.

Citation.

SFEC. 2002. Investigation of methods to estimate mortalities of unmarked salmon in mark-selective fisheries through the use of double index tag groups. TCSFEC(02)-1. pp.87

APPENDIX C. Proposed Application of GSI and Indicator Stock Data[1]

Estimating Chinook Salmon Terminal Runs and Escapements Using Indicator Stock CWT Recovery Data and Catch Estimates from Genetic Stock Identification Programs

Approach

The Pacific Salmon Commission (PSC) hatchery chinook salmon indicator stock program provides recovery data for coded-wire tag (CWT) fish in ocean fisheries and in terminal areas. Backward reconstruction of the tagged cohort abundances from the CTC cohort analyses provides stock- and brood year-specific maturation rates at age. These maturation rates can be applied to the age- and brood year-specific CWT recoveries to estimate the ocean catch of maturing fish (i.e., ocean recoveries of fish that would otherwise have returned to the terminal area in the current year). These data can be used to estimate the fishery and age specific exploitation rates. These hatchery stock exploitation rate data are considered representative of wild stock exploitation rates in PSC stock assessments and in PSC management regimes that do not incorporate mark-selective fisheries.

A genetic stock identification (GSI) program has been implemented in the Southeast Alaska (SEAK) troll fishery over the past several years. Estimates were based upon electrophoresis techniques for several years. The program is currently being converted to the coast-wide micro-satellite methodology sponsored by the chinook Technical Committee (CTC). This program provides independent estimates of stock-specific legal catches in the SEAK fisheries.

Assuming that a natural salmon stock's vulnerability to and distribution in the ocean fishery is similar to that of an associated hatchery indicator stock (the gorilla assumption), the stock- and brood year-specific exploitation rates available from the PSC hatchery indicator stock program can be used as estimates of stock-specific exploitation rates for a natural stock. Coupling the "gorilla assumption" with GSI-based estimates of stock-specific ocean catch provides a means of estimating terminal runs or escapements of natural stocks of chinook salmon.

Variables and notation used below follows the CTC documentation of cohort analysis. Fishery (f)- and stock (s)-specific subscripts are omitted for simplicity but are implicit. Conceptually, the idea is to expand the legal catch of a natural stock, estimated using GSI methods, to the terminal run or escapement of the natural stock based on the estimated maturing portion of legal catch and a quasi-exploitation rate (ratio of the brood year-specific mature catch to the brood tear-specific terminal run size, $RatioMatTerm_{by\ y\text{-}t}$) for an associated CWT indicator stock. The method assumes that brood-year-specific

[1] John Clark, Alaska Fish and Game.

exploitation rates, maturation rates, and ocean age composition are identical for the indicator stock and the associated natural stock of interest.

The ratio of estimated (expanded) ocean recoveries of maturing fish to estimated terminal recoveries of mature fish is calculated from CWT recoveries for the indicator stock:

$$RatioMatTerm_{by\ y\ i} = {R_{by\ y\ i} MatRte_{by\ y\ i}} \Big/ {TR_{by\ y\ i}} \qquad (1)$$

where $MatRte_{by\ y\text{-}i}$ is age- (brood year-) specific maturation rate, $R_{by\ y\text{-}i}$ are the estimated recoveries in ocean fisheries, and $TR_{by\ y\text{-}i}$ are estimated recoveries in terminal areas.

The terminal run ($MatRun_{by\ y\text{-}i}$) of the natural stock is estimated based on applying $RatioMatTerm_{by\ y\ i}$ to the estimated age-specific mature catch ($MatCat_{by\ y\text{-}i}$) from the natural stock (equation (2)). The estimated mature catch is estimated from the GSI-based estimate of total legal catch of the natural stock and estimated age composition of the CWT recoveries in year *y* (see equation (4)) and estimated age- (brood year-) specific maturation rates for the CWT indicator stock (equation (3)).

$$MatRun_{by\ y\ i} = {MatCat_{by\ y\ i}} \Big/ {RatioMatTerm_{by\ y\ i}} \qquad (2)$$

$$MatCat_{by\ y\ i} = LEGCat_{y} * AgeComp_{y,i} * MatRte_{by\ y\ i} \qquad (3)$$

$$AgeComp_{y,i} = {R_{by\ y\ i}} \Big/ {\sum_{i} R_{by\ y\ i}} \qquad (4)$$

Example: North Oregon Coast Chinook Stock & Southeast Alaska Genetic Stock Identification Estimates

As an example of the methodology, an estimate of the North Oregon Coastal (NOC) terminal run in 2001 was made based on the CWT recoveries from the Salmon River Hatchery stock of fall chinook salmon, the NOC indicator stock (Table C1). Age composition of total estimated ocean recoveries from the indicator stock was used to estimate age composition of the NOC legal catch. The total estimated ocean recoveries were converted to estimated maturing recoveries by applying age- and brood year-specific maturation rates (Table C2). Ratios of estimated mature recoveries to estimated terminal recoveries were calculated for the age/brood years present in the SEAK troll fishery (Table C2).

The estimate of the NOC legal catch in the SEAK troll fishery based on GSI methods for the 2001 calendar year was **25,660** chinook salmon. NOC fish are present in the SEAK fishery catches primarily in the July and in fall. Thus, estimates of NOC terminal runs

could be made from the total SEAK troll catch, from the July troll catch, or from the fall troll catch. A worksheet detailing the estimation process for 2001 using the annual SEAK troll data (July + fall) in 2001 is provided in Table C3. The GSI-based catch is converted to catch by age based on CWT ages, then is converted to mature catch based on maturation rates. Then the terminal run by age is estimated by applying the appropriate age specific ratio of SEAK troll mature catch to terminal run catch.

The 2001 terminal run estimate so derived is **244,178** chinook salmon (Table C3). The 2001 NOC spawning escapement reported by Oregon Department of Fisheries and Wildlife (ODFW) is 100,900. Terminal sport harvest for 2001 is not available; however, the magnitude of the NOC terminal sport harvest has ranged from 21,000 to 49,000 in the most recent 5 year period. Thus the total terminal run will probably be estimated somewhere between 120,000 and 150,000 chinook, or about 60% of the estimate developed herein. Note that the ODF&W estimate of NOC escapement is based upon average density of observed chinook salmon per mile times number of river miles and is also adjusted by several "fudge" factors. Comparisons of escapement estimates developed through the ODFW technique to several recent mark-recapture estimates funded by the CTC indicates the ODFW technique is not precise and may also be significantly biased for some of the rivers in the complex. Thus it is difficult to judge whether or not the estimate of 244,178 chinook developed herein is too low, too high, or about right.

Table C1. **Total CWT recoveries from the Salmon River Hatchery indicator stock, 1997 –2002 catch years, by fishery, terminal catch, terminal escapement, and age composition of SEAK fishery recoveries for brood years in the 2001 and 2002 calendar year fishery.**

Year	Brood Year	Winter-Spring Troll CWT Recov.	June Troll CWT Recov.	July Troll CWT Recov.	Fall Troll CWT Recov.	Total SEAK Troll CWT Recov.	Other Ocean Fisheries CWT Recov.	Terminal Catch CWT Recov.	Terminal Escapement CWT Recov.	SEAK Troll Age Comp	July Troll Age Comp	Fall Troll Age Comp
1997	1995	0	0	0	0	0	0	18	30			
1998	1995	0	0	0	6	6	11	66	146			
1998	1996	0	0	0	0	0	0	35	111			
1999	1995	0	0	53	37	90	36	157	243			
1999	1996	0	0	3	10	13	25	128	240			
1999	1997	0	0	0	0	0	8	127	53			
2000	1995	0	0	41	46	87	26	85	168			
2000	1996	0	0	77	74	151	59	201	523			
2000	1997	0	0	0	87	87	34	219	789			
2000	1998	0	0	0	0	0	0	34	136			
2001	1995	0	0	5	3	8	6	0	11	0.02	0.02	0.01
2001	1996	0	0	36	16	52	26	71	196	0.12	0.17	0.07
2001	1997	3	0	160	174	337	204	581	2,339	0.77	0.78	0.75
2001	1998	0	0	5	38	43	60	175	814	0.1	0.02	0.16
2001	1999	0	0	0	0	0	0	127	210	0	0	0
2002	1996	0	0	0	0	0	3	0	0	0	0	0
2002	1997	4	0	139	92	235	186	348	153	0.36	0.45	0.28
2002	1998	1	0	171	214	386	248	666	525	0.6	0.55	0.65
2002	1999	0	0	2	22	24	32	504	908	0.04	0.01	0.07

Table C2. **Estimated mature CWT recoveries from Salmon River Hatchery indicator stock, 1997 –2002 calendar years, by fishery, terminal catch, terminal escapement, exploitation rate for SEAK troll fisheries, and ratio of mature catch to terminal run recoveries for broods in the 2001 and 2002 calendar year fisheries.**

Year	Brood Year	Maturing Recoveries								Ratio of Mature Catch to Terminal Run		
		Winter-Spring Troll	June Troll	July Troll	Fall Troll	SEAK Troll	Other Ocean Fisheries	Terminal Catch	Terminal Escapement	SEAK Troll Fishery	July Troll Fishery	Fall Troll Fishery
1997	1995	0	0	0	0	0	0	18	30	0	0	0
1998	1995	0	0	0	1	1	2	66	146	0	0	0
1998	1996	0	0	0	0	0	0	35	111	0	0	0
1999	1995	0	0	25	18	43	17	157	243	0.11	0.06	0.04
1999	1996	0	0	1	2	2	5	128	240	0.01	0	0.01
1999	1997	0	0	0	0	0	1	127	53	0	0	0
2000	1995	0	0	37	41	78	23	85	168	0.31	0.15	0.16
2000	1996	0	0	50	48	98	38	201	523	0.14	0.07	0.07
2000	1997	0	0	0	10	10	4	219	789	0.01	0	0.01
2000	1998	0	0	0	0	0	0	34	136	0	0	0
2001	1995	0	0	5	3	8	6	0	11	0.73	0.45	0.27
2001	1996	0	0	36	16	51	26	71	196	0.19	0.13	0.06
2001	1997	1	0	63	69	133	80	581	2,339	0.05	0.02	0.02
2001	1998	0	0	1	4	5	7	175	814	0	0	0
2001	1999	0	0	0	0	0	0	127	210	0	0	0
2002	1996	0	0	0	0	0	3	0	0			
2002	1997	4	0	124	82	209	165	348	153	0.42	0.25	0.16
2002	1998	0	0	67	84	152	98	666	525	0.13	0.06	0.07
2002	1999	0	0	2	22	24	32	504	908	0.02	0	0.02

Table C3. Estimated NOC chinook salmon terminal run in 2001 based on Salmon River Hatchery CWT recoveries and GSI catch estimates of NOC chinook salmon in the SEAK troll fishery (July + fall).

Year	Brood Year	Age	Age Composition (Total Fish)	GSI Catch (Total Fish)	Maturation Rate (Total Fish)	GSI Mature Catch	Ratio of SEAK Troll to Terminal Run (Maturing Fish)	Estimated Terminal Run (Total Fish)
2001	1995	6	0.018	467	1.000	467	0.727	642
2001	1996	5	0.118	3,033	0.988	2,995	0.192	15,571
2001	1997	4	0.766	19,653	0.394	7,737	0.045	170,289
2001	1998	3	0.098	2,508	0.113	284	0.005	57,677
2001	1999	2	0.000	0	0.068	0	0.000	
		Total		**25,660**				**244,178**

APPENDIX D. Current Status of Pacific Salmon Genetic Databases.

I. MICROSATELLITES (Standardization required)

Chinook: The Chinook Technical Committee has funded a multi-agency project to develop a single standardized microsatellite database. Funded collaborators include: ADFG, NMFS-Auke Bay, NMFS-NWFSC, NMFS-SWFSC, OSU, WDFW, CDFO, Univ. of Idaho, IDFG, CRITFC. Non-funded collaborators include: USFWS-AK, USFWS-Abernathy. Each collaborating laboratory has an independent chinook baseline not reviewed here.

Coho: There are six independent microsatellite baselines that are unstandardized: CDFO, NMFS-NWFSC, NMFS-SWFSC, OSU, USFWS-AK, WDFW. WDFW and CDFO are currently funded by the Southern Panel to develop a new microsatellite panel (12-18 loci) that can be run in both laboratories to address PSC issues in Washington and British Columbia.

Chum: There are three independent microsatellite baselines that are unstandardized: CDFO, USFWS-AK, and WDFW. WDFW and CDFO are currently funded by the Southern Panel to develop a new microsatellite panel (12-18 loci) that can be run in both laboratories to address PSC issues in Washington and British Columbia. University of Alaska Fairbanks is currently funded by the Bering Sea Fisheries Association to develop a panel of loci that could be used to address Bering Sea issues.

Sockeye: There are five independent microsatellite baselines that are unstandardized: CDFO, ADFG, University of Washington, USGS-AK, WDFW.

Steelhead: There are six independent microsatellite baselines that are unstandardized: CDFO, NMFS-NWFSC, NMFS-SWFSC, USFWS-AK, WDFW, USGS-AK. Efforts are underway to develop a standardized microsatellite panel among NMFS-NWFSC, USFWS Abernathy, University of Idaho, CRITFC, IDFG.

II. SNPs (Standardized by Definition)

Chinook: ADFG in collaboration with NMFS-NWFSC has identified over 50 SNPs; about 35 assays are currently adapted for high-throughput analyses. The USCTC has very recently funded development of an additional set of 45 SNP markers for high-throughput analyses as well as screening of 500 individuals in seven laboratories by GAPs laboratories.

Chum: ADFG in collaboration with NWFSC, Hokkaido University, Fisheries Agency of Japan, and NMFS-NWFSC have identified over 50 SNPs; about 37 assays are currently adapted for high-throughput analyses. University of Alaska, Juneau Center, is currently funded by the Bering Sea Fisheries Association to develop a panel of loci that could be used to address Bering Sea issues.

Sockeye: ADFG in collaboration with NMFS-Auke Bay has identified over 50 SNPs; 27 assays are currently adapted for high-throughput analyses.

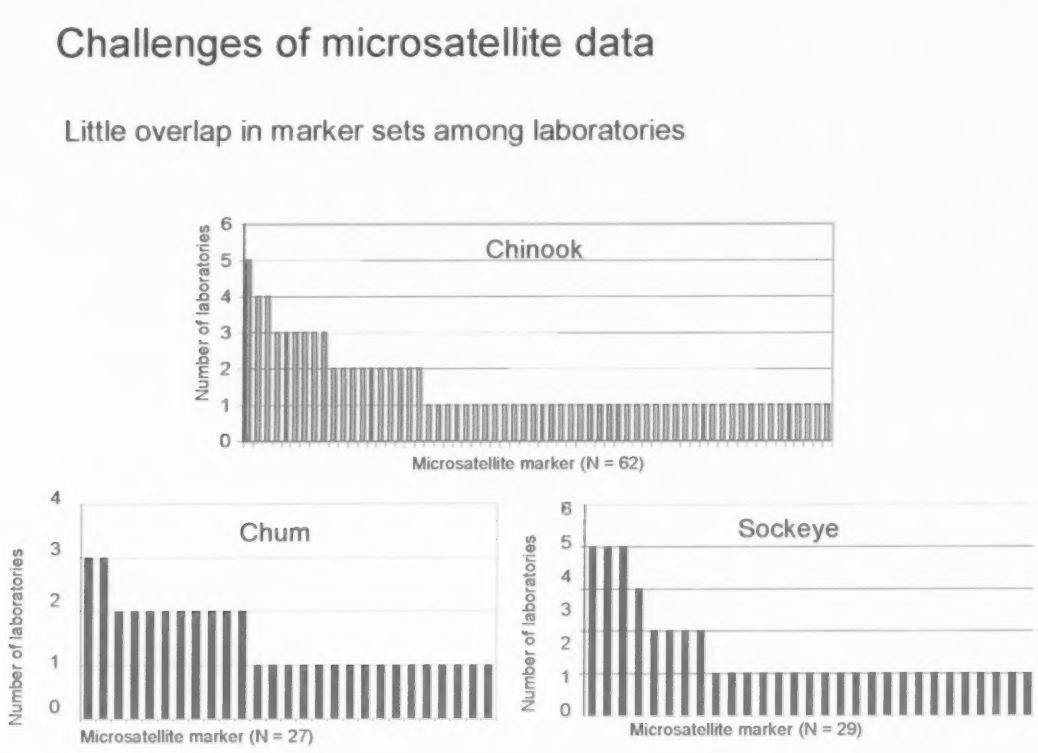
Steelhead: Marker development is underway at NMFS-SWFSC.

Coho: No marker or baseline development effort is underway although ADFG is considering initiating a program.

III. ARCHIVED MATERIAL

The CTC project includes provisions for archiving DNA material from approximately 150 chinook per baseline population. No coordinated archival effort is underway for any other species of salmon These archive collections are needed for use in expanding the database to verify alleles for the same core set of samples and thus avoiding the costly recollection of tissues. Using a core set of samples also avoids the confounding statistical issue of varying sets of individuals for the same spawning population.

IV. OVERLAP OF MARKERS USED IN EXISTING MICROSATELLITE BASELINES.



V. Laboratory Abbreviations Used:

ADFG	Alaska Department of Fish and Game, Anchorage
CDFO	Pacific Biological Station, Nanaimo
CRITFC	Columbia River Intertribal Fisheries Commission
IDFG	Idaho Department of Fish and Game
NMFS-Auke Bay	NMFS, Alaska Science Center, Auke Bay
NMFS-NWFSC	NMFS, Northwest Fisheries Science Center, Seattle
NMFS-SWFSC	NMFS, Southwest Fisheries Science Center, Santa Cruz
OSU	Oregon State University, Newport
UAF	University of Alaska Fairbanks, Juneau
USFWS- AK	USFWS, Alaska Region, Anchorage
USFWS-Abernathy	USFWS, Abernathy Technical Center, Abernathy, WA
USGS – Anchorage	Alaska Science Center, Anchorage
WDFW	Washington Department of Fish and Game, Olympia
WSU – Vancouver	Washington State University, Vancouver

VI. DETAILS CONCERNING PACIFIC RIM DNA BASELINES.

Species	Baseline #	Home Laboratory	Marker Type	Coverage	Labs hoping to standardize with this baseline	Successful standardization	Comments
COHO	1	CDFO/ Nanaimo	Microsat.	Pacific NW plus outliers	WDFW		Funded by Southern Panel to standardize with WDFW
	2	NMFS-NWFSC	Microsat.	Col. R , PNW	CRITFC, USFWS Abernathy		
	3	NMFS-SWFSC	Microsat.	CA, outliers			
	4	Oregon State University	Microsat.	OR extensive, outliers CA, WA			
	5	USFWS- Alaska Region	Microsat.	W. AK, outliers in AK			
	6	WDFW	Microsat.	WA	CDFO		Funded by Southern Panel to standardize with CDFO
CHUM	1	ADFG	SNP		NMFS-ABL, UAF	NMFS-NWFSC, Hokkaido Univ. and Fisheries Agency of Japan (FAJ)	Markers developed with NWFSC, Hokkaido Univ, FAJ; >50 SNPs developed, 37 assays running
	2	CDFO/ Nanaimo	Microsat.	BC, outliers	USFWS		Funded by Southern Panel to standardize with WDFW
	3	Univ. of Alaska	SNP		ADFG		Funded by Bering Sea Fisherman's Association for marker development
	4	Univ. of Alaska	Microsat.				Funded by Bering Sea Fisherman's Association for marker development
	5	USFWS- Alaska Region	Microsat.	Yukon R., outliers	CDFO		

Species	Baseline #	Home Laboratory	Marker Type	Coverage	Labs hoping to standardize with this baseline	Successful standardization	Comments
	6	WDFW	Microsat.	WA, outliers			Funded by Southern Panel to standardize with CDFO
SOCKEYE	1	ADFG	Microsat.	Russia, W. AK			
	2	ADFG	SNP	Russia, W. AK		NMFS-Auke Bay	>50 SNPs identified, 27 assays running
	3	CDFO/ Nanaimo	Microsat.	BC, SE AK, outliers			
	4	Univ. of Washington	Microsat.	Bristol Bay			
	5	USGS - Anchorage	Microsat.	Bristol Bay, outliers			
	6	WDFW	Microsat.	WA			
CHINOOK	1	CTC Coast-wide	Microsat.	SE AK to California, Copper River, Yukon, Kuskokwim,	GAPs[1]		Funded by Chinook Technical Committee to develop standardized baseline
	2	ADFG	SNP	Yukon, Kuskokwim, Copper River, outliers	GAPs[2]	NMFS-Auke Bay, NMFS-NWFSC, CRITFC	>50 SNPs identified, 35 assays running
	3	CTC Coast-wide	SNP	SE AK to California	GAPs[2]		Funded by Chinook Technical Committee to develop 45 SNPs and to assay 500 individuals in each of seven laboratories
	4 To 15	ADFG, NMFS-Auke Bay, NMFS-NWFSC, NMFS-SWFSC, Oregon State University, WDFW, CDFO, Univ. of Idaho, IDFG, CRITFC, USFWS-Anchorage, USFWS-Abernathy	Microsat.	California to Yukon			These various microsatellite baselines all developed independently with various markers and various levels of coast-wide coverage.

Species	Baseline #	Home Laboratory	Marker Type	Coverage	Labs hoping to standardize with this baseline	Successful standardization	Comments
STEELHEAD	1	CDFO/ Nanaimo	Microsat.	BC, outliers			
	2	NMFS-NWFSC	Microsat.	Col. River, outliers	USFWS-Abernathy, Univ. of Idaho, CRITFC		
	3	NMFS-SWFSC	Microsat.	CA			
	4	USFWS- Alaska Region	Microsat.	Alaska			
	5	USGS - Anchorage	Microsat.	Alaska, CA, Col. R.			
	6	WDFW	Microsat	WA, outliers			

[1] Original GAPs laboratories
[2] Original GAPs laboratories as well as two new member laboratories—IDFG and WSU Vancouver.

APPENDIX E. Chinook Salmon CWT indicator stock releases.

Number of tagged and untagged chinook salmon released for CTC exploitation rate indicator stocks. Indicator stock names and tag codes taken from CTC (TCCHINOOK 2004) Tables A.3 and Appendix L. Data downloaded from RMIS database 4/25/2005

CTC Group	Run	Release age	Hatchery	Brood Year													
				1996			1997			1998			1999			2000		
				Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag
Alaska Springs	Spring	Yearling	CRYSTAL LAKE	46,166	558,737	5,187	60,547	603,443	6,925	61,757	645,254	6,558	62,399	526,473	6,856	70,519	493,355	1,366
			CRYSTAL LK/NEETS BAY	34,541	364,346	5,391	39,980	302,362	4,992	44,326	376,619	858	41,960	371,991	2,378	46,730	405,009	905
			DEER MOUNTAIN	21,499	79,288	529	17,447	31,403	2,561	16,887	68,580	4,791	21,589	67,413	486	20,644	73,315	2,067
			LITTLE PORT WALTER	98,736	8,973		101,718	4,802		131,459	2,637		105,676	3,150				
			NEETS BAY	19,377	118,655	78	21,159	172,586	388									
			WHITMAN LAKE	76,565	636,458	308	76,736	665,039	154	76,236	703,054	460	76,750	704,889	1,011	77,114	609,307	3,213
Central Coastal BC	Summer	Fingerling	H-SNOOTLI CR	51,334	681,119	6,670	58,622	561,540	1,197	52,918	292,075		51,104	676,001	516			
	Summer	Fingerling	H-SNOOTLI CR										28,833	108	291			
Lower Strait of Georgia	Summer	Fingerling	H-PUNTLEDGE R	28,448	61,477	959	28,802	121,806	1,484	28,537	197,525	1,871	63,794	100,131	3,014	59,346	273,736	1,261
	Fall	Fingerling	H-BIG QUALICUM R	209,831	3,878,669	3,848	201,752	3,351,493	1,921	203,266	3,550,597	4,785	202,938	3,432,113	5,390	191,496	2,716,956	1,935
North and Central BC	Summer	Fingerling	H-TERRACE	83,745	1,651		83,334	2,278		200,399	401		146,296	1,473		210,061	3,726	205
Upper Strait of Georgia	Fall	Fingerling	H-QUINSAM R	229,166	1,729,021	2,143	236,352	1,484,371	4,695	190,383	2,015,389	9,850	223,478	2,284,504	183	229,498	2,048,171	644
WCVI	Fall	Fingerling	H-ROBERTSON CR	175,368	1,938,652	45	199,075	8,130,522	704	201,794	7,373,794		200,300	7,475,855	412	195,663	4,775,477	506
Oregon Columbia River	Spring	Fingerling	DEXTER PONDS (WILLAM	31,797	4,436	216,923	240,805	7,928										
			MCKENZIE HATCHERY							28,965	217,058	113	28,152	200,065	13,853			
			SOUTH SANTIAM HATCH	52,336	2,829	242,445				78,531	516,647	11,129	52,509	234,099	5,539			

CTC Group	Run	Release age	Hatchery	Brood Year													
				1996			1997			1998			1999			2000		
				Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag
			WILLAMETTE HATCHERY				29,836	238					46,869	192,185	12,145			
		Yearling	DEXTER PONDS (WILLAM				922,851	22,690	2,618	59,132	1,046,915							
			MARION FORKS HATCH							30,398	592,794	41,337	30,900	615,784	16,431			
			MCKENZIE HATCHERY	81,960	2,555		123,278	1,314	893	89,618	326,362	7,880	94,663	421,739	12,057			
			SOUTH SANTIAM HATCH	60,777	3,564	614,977							59,734	310,749	46,911			
			WILLAMETTE HATCHERY	31,695	1,026	519,682	284,258	7,264	512				23,988	480,506	40,864			
	Fall	Fingerling	BIG CR HATCHERY	217,574	863	5,742,681	218,967	749	5,646,458	225,527	5,097	5,574,297	215,198	3,554	5,600,509	224,267	828	4,311,525
Northern Oregon Coast	Fall	Fingerling	SALMON R HATCHERY	194,096	1,545	618	179,888	11,453	1,347	190,423	4,775	398	196,302	2,190		205,725	436	
Washinton Columbia River	Summer	Fingerling	WELLS HATCHERY				513,016	13,485					340,755	13,239		490,873		
	Fall	Fingerling	RINGOLD SPRINGS HATCHERY				114,382	33,621	1,436	197,337	3,066,355	8,272	207,620	3,007,910	1,347	217,522	2,575,661	
	Fall	Fingerling	NA				48,109	664		28,768	614		47,128			29,138		
	Fall	Fingerling	PRIEST RAPIDS HATCHERY	192,726	4,746,410	5,075												
	Summer	Fingerling	WELLS HATCHERY							354,950	8,255							
		Yearling	WELLS HATCHERY	189,531	3,306								304,511	6,151		328,308	7,591	
	Fall	Fingerling	SPRING CR NFH	432,187	13,899,602	15,095	441,373	4,497,401	10,680,655	429,868	10,151,341	10,866	399,408	49,011	15,617,526	440,787	9,169	10,119,854
Hood Canal	Fall	Fingerling	GEORGE ADAMS HATCHRY	217,308	1,584,997	7,171	222,990	3,638,768	2,566	223,343	2,010		208,330	9,065		121,294	487	
North and Central Puget Sound	Fall	Fingerling	SOOS CREEK HATCHERY	198,332	3,028,367	3,434	203,028	1,775		189,430	6,833		193,355	2,945		194,248	2,758	
	Fall	Fingerling	GROVERS CR HATCHERY	201,607	381,160	8,182	186,612	299,518	22,435	198,868	370,366	10,247	181,132	19,457		203,754	25,211	1,634
	Fall	Fingerling	SAMISH HATCHERY	199,351	694,200	1,528	101,754	2,725,487	339	196,029	748		178,661			146,129	2,155	
	Summer	Fingerling	WHITEHORSE POND	202,123	15,241		45,196	2,375		173,001	13,840							
South	Fall	Yearling	PERCIVAL	190,756	229		190,356	944										

CTC Group	Run	Release age	Hatchery	Brood Year													
				1996			1997			1998			1999			2000		
				Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag	Tagged and Clipped	Clipped, no tag	No clip, no tag
Puget Sound			COVE NET PN TUMWATER FALLS HATCH										67,926	273				
	Fall	Fingerling	NISQUALLY HATCHERY	226,046	2,710,512	8,442	207,617	2,445,994	11,389	202,103	1,088,683	872,214	199,030	25,103		79,065	472,418	24,239
Washington Coastal	Fall	Fingerling	SALMON R FISH CULTUR	206,522	61,053	13,416	200,731	130,475	15,574	175,687	117,009	31,004	179,685	1,863	11,877	186,609	18,231	50,971
	Fall	Fingerling	MAKAH NFH ON SOOES R				67,595	1,326	762,534	58,759	7,997	750,944	129,407	3,047	985,101	119,440	14,661	858,834
White River	Spring	Yearling	HUPP SPRINGS REARING	31,792	1,595		28,102	175	685									

Citation.

TCHINOOK 2004. Annual Exploitation Rate Analysis and Model Calibration. PSC Joint Chinook Technical Committee Report. TCHINOOK (04)-4.

APPENDIX F. Alternative Schemes for Estimating Total Age-Specific Non-landed Mortalities to Unmarked Salmon Subject to a Mixture of Non-Selective and Mark-Selective Fisheries[2]

CONTEXT

As noted in Appendix A, the performance of the DIT approach to estimation of total non-catch mortalities should be very sensitive to the numbers of fish released and to the magnitude and relative size of selective fisheries as compared to non-selective fisheries. If the number and magnitude of selective fisheries are small compared to nonselective fisheries and the DIT release groups sizes are relatively small (say, 100,000 fish each), then the approach described in Appendix A will not perform well.

The Appendix A approach relies importantly on detection of a difference in "escapement rates" of marked and unmarked DIT groups resulting from a mixture of non-selective and mark-selective fisheries. Theoretically, if two groups of marked and unmarked fish are reared and released in identical fashion, the escapement rate (freshwater returns/release group size) for the unmarked group should exceed that of the marked group.

The purpose of this appendix is to present an outline of SIT+ (a single CWT release coupled with otolith marking) as a potential alternative to CWT-DIT as a means of estimating stock-age-fishery exploitation rates for unmarked fish in Mark-Selective Fisheries. The estimation scheme relies on release of one release group of marked fish containing a CWT combined with large release sizes of unmarked, but otolith tagged fish. On return to hatcheries, otolith marked fish can be identified, thus allowing a much improved estimate of escapement rate for the unmarked fish.

We believe that the difference between escapement rates for the two groups can be used to obtain an estimate of total non-landed mortalities suffered by the unmarked group. Unlike the DIT approach, however, these estimated total non-landed mortalities will not be approximately unbiased, but we believe that bias may be small so long as ocean fishery exploitation rates remain modest.

Background:
The Selective Fishery Evaluation Committee (SFEC) of the Pacific Salmon Commission has focused its efforts on estimating stock-age-fishery exploitation rates for unmarked fish in mark-selective fisheries (MSFs) through the use of data collected from Double Index Tagging (DIT) experiments. Under DIT, two groups of fish with different CWTs are released, identical except that the adipose fin is removed from fish in one group and left intact in the other. Electronic tag

[2] G. Morishima

detection (ETD) is employed to recover CWTs. Methods to estimate age-specific exploitation rates of unmarked fis in MSFs are based on differences in CWT recovery patterns between the paired DIT groups.

Concerns with the DIT approach have centered on three primary areas:

1. DIT increases marking costs – effectively, doubling the number of CWTs released for indicator stocks

2. Sampling costs to recover DIT fish are substantially higher. Some agencies prefer to rely upon visual sampling and are reluctant to employ ETD equipment due to cost and operational considerations – consequently, CWTs from unmarked DIT fish are not recovered in non-selective fisheries without ETD.

3. The capacity of DIT to produce reliable estimates of fishery-specific exploitation rates for individual stocks in practice is uncertain. DIT methods depend critically upon a set of assumptions (e.g., known and constant release mortality rates) and estimation methods can lead to results that are inconsistent with observational data. SFEC has not been able to develop methods to accurately estimate age-fishery specific exploitation rates on unmarked DIT fish when multiple mark-selective fisheries affect a stock or when sub-stocks are subjected to different fishing patterns (e.g., a portion of a stock may migrate outside Vancouver Island where there are no mark-selective fisheries while another portion may resides inside Vancouver Island where a mark-selective fishery occurs). Further, the SFEC has not investigated the potential impacts of other sources of mortality believed to be significant in the conduct of MSFs, such as drop-off, mark-recognition error, and unmarked retention error.

Advantages and disadvantages of the SIT+ approach are summarized in Table F1.

Table F1. Summary of Advantages and Disadvantages of SIT+ System

Advantages	Disadvantages
SIT+ allocates observed differences in return rates of release groups. SIT+ requires estimates of mortalities of unmarked (*U*) fish to be consistent with observational data. Differences in exploitation rates would be estimated with greater precision because more marked fish would be recovered in escapements, compared to DIT experiments. Differences in return rates would reflect cumulative effects of process error and all sources of fishing mortality including release, drop-off, mark-recognition, and unmarked retention error rates. Although estimates of stock-age-fishery mortality rates of unmarked fish cannot be directly validated, in cases where the impact of MSFs is small relative to total fishing mortality, the uncertainty surrounding such estimates should be comparable to that expected of DIT-based estimation methods and may not be of sufficient magnitude so as to be of significant concern for management.	Because incidental mortalities are allocated via algorithms, this approach can potentially produce biased and uncertain estimates of fishery-specific exploitation rates of unmarked fish. The apriori assumptions embedded within the estimation methods and allocation algorithms would generate estimates of exploitation rates that cannot be directly evaluated. Uncertainty would have to be accepted as a matter of course.
Otolith marking costs would be relatively low so the size of the unmarked (mass marked) otolith release could be quite large if desired. Cost-savings in marking could be used to reduce the uncertainty surrounding estimates of age-fishery specific estimates of exploitation rates resulting from rare event effects (e.g., the size of the MCWT group could be doubled to increase the number of CWTs recovered in individual strata and improve the precision of CWT-based estimates). If the size of the *U* group is also increased (relative to a normal DIT-CWT based release) problems of rare event random effects of fishing would also be reduced.	Some reduction in mark rates in MSF would occur if the *U* release size is increased (relative to a DIT-type release) to improve the precision of MSF impacts.
Maintain the ability to continue to use visual sampling methods to collect CWTs. Eliminate the need for sampling unmarked fish in the catch, addressing the information void resulting from the use of visual sampling regimes in Alaska and Canada.	Agencies relying on visual methods to recover CWTs would need to process a large number of snouts. ETD could still be employed for marked fish to minimize the number of snouts taken and processed. No direct fishery estimates of encounters of the *U* release group would be available in any preterminal fisheries
Since sampling for differences in *U:M* ratios would be restricted to terminal areas, limitations on the number of distinct otolith marks should not be a problem.	Impacts of MSF would be inferred from the cohort analysis on recoveries of the MCWT group.

Estimation Methods[3]

A full cohort analysis of the ***MCWT*** group would be performed, providing an estimate of survival during the first year of ocean residence, fishery-age specific estimates of exploitation rates and age-specific estimates of maturation rates.

[3] The equations presented in this Appendix can be simplified. However, in the interests of clarity, the equations are provided in step-wise form.

Coho Salmon

Single Otolith Mark

a. Mass mark the entire release except for a group of fish that would be otolith marked (U). Place CWTs in a portion of the mass marked fish (***MCWT***).

b. Rely upon differences in hatchery escapement rates between the ***MCWT*** and ***U*** groups to estimate cumulative effects of mark-selective fisheries (MSF).

c. Use an algorithm to estimate stock-age-fishery specific exploitation rates for all MSF and non-selective fisheries, including allocation of observed differences in return rates of the *U* and ***M*** groups to individual MSFs.

The following example illustrates how the marking and release groups might be structured under this approach for a hatchery that produces 6,000,000 coho smolts. Under the SIT-otolith system, the release could look like:

Group	MCWT	M	U
Mark(s)	CWT+MM	MM	Otolith
Number	40,000	4,960,000	1,000,000

For comparison, a CWT-based DIT system would look like this:

Group	MCWT	M	UCWT
Mark(s)	CWT A +MM	MM	CWT B
Number	40,000	5,920,000	40,000

Because the exploitation of coho salmon occurs predominantly during the last few months of life, the mathematics of exploitation are straightforward.

Estimate the number of fish that survive to recruitment. From cohort analysis, estimate the survival rate for the MCWT group and assume that the ***U*** group survives at the same rate.

$$N_u = RS_U * s_{mcwt}$$

Estimate the escapement of ***U*** (ESC_U) by reading otolith patterns at the hatchery (note adjustments could be incorporated to adjust for straying). Compute the escapement rates as:

$$EscR_U = \frac{ESC_U}{N_U} = (1 - \sum_{f \in msf} ER_{U,f} - \sum_{f \in nsf} ER_{U,f}) \qquad \text{eq co-1}$$

Now, assume that the exploitation rates of the ***MCWT*** and ***U*** groups in non-selective fisheries are identical. Note that this assumption cannot, in general, be assumed to hold. This can be readily illustrated through the use of a simple gauntlet fishery in which one fishery operates before another. For example, assume that both groups are subjected first to a MSF than to a NSF, that there are 1000 fish from each group alive when the first fishery begins, that the harvest rate for

marked fish in each fishery is 0.20, that the release mortality rate on marked fish =0.10, and that there is no natural mortality during the fisheries. True fishery harvest rates (the proportion of a population available to a fishery which is killed by that fishery), catches, and incidental mortalities are depicted in the following table:

	Marked Fish	UnMarked Fish
Initial Cohort	1000	1000
MSF Harvest Rate	0.20	0.02 = 0.20*0.10
MSF Mortality	200	20
Remaining after MSF	800	980
NSF Harvest Rate	0.20	0.20
NSF Mortality	160	196
Escapement	640	784
NSF Exploitation Rate	0.160 = 160/1000	0.196 = 196/1000

The exploitation rates of the Marked and Unmarked groups in the NSF are not identical. If, however, the sequence of the fisheries is reversed, the exploitation rates in the NSF would be identical. Consequently, the validity of the assumption of equal exploitation rates in NSFs depends on the fishing pattern.

	Marked Fish	UnMarked Fish
Initial Cohort	1000	1000
NSF Harvest Rate	0.20	0.20
NSF Mortality	200	200
Remaining after MSF	800	800
MSF Harvest Rate	0.20	0.02 = 0.20*0.10
MSF Mortality	160	16
Escapement	640	780
NSF Exploitation Rate	0.200 = 160/1000	0.200 = 200/1000

If fishing patterns are known, then algorithms can be developed accordingly. In the absence of such information, this assumption will likely be in error. The fishery harvest rates employed in the example are intentionally extreme for illustrative purposes. When ocean fishery exploitation rates are modest and the relative magnitude of mark-selective fisheries is small compared to non-selective fisheries, the assumption will not likely be far from correct.

The difference between the escapement rate of U and the escapement rate of the ***MCWT*** group from the non-selective fisheries (***NSFs***) represents the cumulative impact of the ***MSFs***.:

$$MSFER_U = (1 - \sum_{f \in nsf} ER_{U,f}) - EscR_U = \sum_{f \in msf} ER_{U,f} \qquad \text{eq co-2}$$

The MSF mortalities of the ***U*** group can now be readily estimated as:

$$IM_U = MSFER_U * N_U \qquad \text{eq co-3}$$

The task is now to allocate this mortality among the MSFs. A variety of algorithms could be employed for this purpose. If, for example, the mortalities are prorated according to assumed

release mortality rates, the cumulative exploitation rate (CER) assuming that ***U*** and ***M*** fish are encountered at the same rate would be:

$$CER = \sum_{f \in msf} ER_{M,f} * sfm_f \qquad \text{eq co-4}$$

And the incidental mortalities for each MSF would be:

$$IM_{U,f} = IM_U * \frac{ER_{M,f} * sfm_f}{CER} \qquad \text{eq co-5}$$

Finally, the exploitation rate of unmarked fish in each MSF would be:

$$ER_{U,f} = \frac{IM_{U,f}}{N_U} \qquad \text{eq co-6}$$

Other, more sophisticated algorithms to allocate estimated incidental mortalities of ***U*** fish in MSFs could be developed.

Example. A hatchery that produces 6,000,000 coho smolts that are marked as indicated in the following table. The fish are subjected to two NSFs and two MSFs (with a release mortality of 10%). Observable values are outlined and results of the cohort analysis are depicted in the shaded cells:

	Cohort Analysis	MCWT	M	U + Otolith
Released		40000	4,960,000	1,000,000
Survival to maturity	**0.10**	4000	496000	100000
Non-selective fisheries				
NSF 1	**0.10**	400	49600	10000
NSF 2	**0.15**	600	74400	15000
Mark-selective fisheries				
Encounters in MSF 1	**0.12**	480	59520	12000
- release mortality in MSF 1				1200
Encounters in MSF 2	**0.15**	600	74400	
- release mortality in MSF 2				1500
Escapement		1920	238080	72300
Escapement rate		0.48		0.723
Exploitation rate in NSF		0.25		0.25
Escapement rate from NSF		0.75		0.75
Exploitation Rate in MSF		0.27	0.27	0.027
Estimated Release Mortalities				2700

From cohort analysis, the survival rate of the MCWT fish is:

$$\frac{400+600+480+600+1920}{40000}=0.10$$

Assuming that the U group survives at the same rate, the initial size of the surviving U fish is 100,000 (0.10*1,000,000).

Using eq co-1, the escapement rate of U = 73200/100000=0.723.

From eq co-2, the exploitation rate of U in MSFs = (1-0.25)-0.723 = 0.027

From eq co-3, the cumulative release mortalities of U in MSFs = 0.027*100000 = 2700

Assuming that the release mortality rate is 10%, eq co-4 would indicate that the

CER = 0.12*.010 + 0.15*0.10 = .027

From equation co-5, the exploitation rate of U in MSF 1 and MSF 2 is then:

$$IM_{U,msf1} = 2700 * \frac{0.12 * 0.10}{0.027} = 1200$$

$$IM_{U,msf2} = 2700 * \frac{0.15 * 0.10}{0.027} = 1500$$

And, finally using co-6, the exploitation rates in the MSFs is:

$$ER_{U,msf1} = \frac{1200}{100000} = 0.012$$

$$ER_{U,msf2} = \frac{1500}{100000} = 0.015$$

Otolith-DIT

In this approach, the CWT-DIT would be replaced with an otolith-DIT system. If the exploitation rates in the MSFs can be estimated using only a single otolith mark, why bother using an otolith-DIT system? There are two reasons: (1) estimates of fishery-specific exploitation rates are derived from estimated recoveries of the MCWT group which are subject to both process and sampling error; and (2) the larger number of otolith marked fish released would result in the recovery of more otolith marked fish in escapements – this would provide a more precise estimate of the escapement rate which would not only reduce uncertainty by increasing precision, but also improve the capacity to detect smaller differences in exploitation rates of the marked and unmarked groups.

a. Mass marked fish and place CWTs in a release group of normal size (**MCWT**). Replace CWT-DIT with Otolith DIT (***M***) and (***U***). Use a distinct otolith mark to identify fish that are not mass marked (***U***). Mass mark the remainder of the release, identifying fish from this group using a different otolith mark (***M***).

b. Estimate the cumulative savings rate of unmarked fish in MSFs as the difference between escapement rates of the ***M*** and ***U*** groups.

c. Estimate the total fishing mortality rate of the ***MCWT*** group in MSFs.

d. Compute the incidental mortality rate of the ***U*** group as the difference between (c) and (b) and convert to the number of incidental mortalities.

e. Use an algorithm to estimate stock-age-fishery specific exploitation rates for all MSF and non-selective fisheries, including allocation of observed differences in return rates of the ***U*** and ***M*** groups to individual MSFs.

The following example illustrates how the marking and release groups might be structured under this approach for a hatchery that produces 6,000,000 coho smolts. Under the SIT-otolith system, the release could look like:

Group	MCWT	DIT-M	DIT-U
Mark(s)	CWT+MM	MM+Otolith A	Otolith B
Number	40,000	4,960,000	1,000,000

For comparison, a CWT-based DIT system would look like this:

Group	MCWT	M	UCWT
Mark(s)	CWT A +MM	MM	CWT B
Number	40,000	5,920,000	40,000

Estimate the survival rate for the ***MCWT*** group and assume that the ***U*** and ***M*** groups survive at the same rate.[4]

$$s = \frac{\sum_{f} \mathrm{Rec}_{MCWT,f}}{RS_{MCWT}}$$

$$N_U = s * RS_U \qquad \text{eq co2-1}$$

$$N_M = s * RS_M$$

Estimate the escapement of ***U*** (ESC_U) and ***M*** (ESC_M) fish by reading otolith patterns at the hatchery. Compute the escapement rates as:

$$EscR_U = \frac{ESC_U}{N_U}$$

$$EscR_M = \frac{ESC_M}{N_M} \qquad \text{eq co2-2}$$

The difference between the escapement rates of the ***U*** and ***M*** groups represents the cumulative rate of savings of the ***U*** group in ***MSFs***:

$$MSR_U = EscR_U - EscR_M \qquad \text{eq co2-3}$$

[4] Estimates of initial cohort sizes of the M and U groups would reflect any errors in the estimate of the MCWT survival rate resulting from sampling programs and cohort reconstruction.

The escapement rates of the ***M*** and ***MCWT*** groups may not be equal due to process and sampling error. If these escapement rates differ, the exploitation rates estimated from cohort analysis of the ***MCWT*** group can be adjusted. Several methods can be employed. The simplest would be to assume that the difference in exploitation rates is due to error that is equally distributed across all fisheries. In this case, the adjustment factor can be estimated from the escapement rates as:

$$\Delta = \frac{1 - EscR_M}{1 - EscR_{MCWT}} \qquad \text{eq co2-4}$$

So the estimated mortality rate of the ***M*** fish in MSFs can be computed as:

$$ER_{M,f} = \Delta * ER_{MCWT,f}$$
$$MER_M = \sum_{f \in msf} ER_{M,f} \qquad \text{eq co2-4a}$$

Another alternative would be to apportion the difference in exploitation rates according to their coefficients of variation. In this method,

$$\Delta = (1 - EscR_M) - (1 - EscR_{MCWT}) = EscR_{MCWT} - EscR_M \qquad \text{eq co2-4b}$$

and the estimated mortality rate of the ***M*** fish in individual fisheries can be computed as:

$$ER_M = \frac{\Delta * CV_{MCWT,f} * ER_{MCWT,f}}{\sum_f CV_{MCWT,f}} \qquad \text{eq co-2-4c}$$

So that the exploitation rate of the ***M*** group in MSFs is:

$$MER_M = \sum_{f \in msf} ER_{M,f} \qquad \text{eq co2-4c}$$

Assuming that the ***M*** and ***U*** groups are exploited at the same rates in non-selective fisheries, the cumulative exploitation rate of the ***U*** group in MSFs can now be estimated as:

$$MSFER_U = MER_M - MSR_U \qquad \text{eq co2-5}$$

The incidental mortalities of the ***U*** group is:

$$IM_U = MSFER_U * N_U \qquad \text{eq co2-6}$$

These incidental mortalities can now be allocated among the MSFs and the MSF mortality rates of the ***U*** group computed using equations co-4 through co-6.

Example. A hatchery that produces 6,000,000 coho smolts that are marked as indicated in the following table. The fish are subjected to two NSFs and two MSFs (with a release mortality of

10%). Observable values are outlined and results of the cohort analysis are depicted in the shaded cells:

	Cohort Analysis	MCWT	M + Otolith A	U (Otolith B)
Released		40000	4,960,000	1,000,000
Survival to maturity	**0.10**	4000	496000	100000
Non-selective fisheries				
NSF 1	**0.10**	400	49600	10000
NSF 2	**0.15**	600	74400	15000
Mark-selective fisheries				
Encounters in MSF 1	**0.12**	480	59520	12000
- release mortality rate in MSF 1	0.10			1200
Encounters in MSF 2	**0.15**	600	74400	
- release mortality rate in MSF 2	0.10			1500
Escapement		1920	238080	72300
Escapement rate		0.48	0.48	0.723

From cohort analysis, the survival rate of the MCWT fish is:

$$\frac{400+600+480+600+1920}{40000}=0.10$$

Assuming that all groups survive at the same rate, the initial size of the surviving ***U*** group = 100,000 = 0.10*1,000,000 and the initial size of the surviving ***M*** group = 496,000 = 0.10*4,960,000.

The escapement rates for the ***U, M, and MCWT*** group are 0.723 (72,300/100,000), 0.48 (238,080/496,000), and 0.48 (1,920/4,000), respectively.

From eq co2-3, the savings rate for the ***U*** group in MSFs = 0.243 = 0.723-0.480.

From eq co2-4, the cumulative exploitation rate of the ***M*** group in MSFs = 0.270 = (((1-0.48)/(1-0.48))*(0.12+0.15).

Since the escapement rates are equal for the ***M*** and ***MCWT*** groups, no adjustment to the fishery exploitation rates estimated from cohort analysis of recovery data for the ***MCWT*** group. From eq co2-5, the cumulative exploitation rate of the ***U*** group in MSFs = 0.027 = 0.270-0.243.

From eq co2-6, the cumulative release mortalities of ***U*** in MSFs = 2700 = 0.027*100000.

Chinook Salmon

Because chinook salmon are exploited at multiple ages and different stages of maturity, the mathematics of estimating age-fishery exploitation rates for a given stock, although analogous to that presented for coho, are more complex.

- Employ a DIT-otolith system.[5] Two groups of fish would be otolith marked and released from a given brood-hatchery. One group would be mass marked (M) while the other would not (U). A portion of the marked fish would be CWT'd (MCWT).[6]

- Rely upon differences in hatchery escapement rates between the M and U groups to estimate cumulative effects of mark-selective fisheries (MSF).

- Use an algorithm to estimate stock-age-fishery specific exploitation rates for all MSF and non-selective fisheries, including allocation of observed differences in return rates of the U and M groups to individual MSFs.

The following example illustrates how the marking and release groups might be structured under this approach for a hatchery that produces 6,000,000 chinook smolts. Under the SIT-otolith system, the release could look like:

Group	MCWT	M	U
Mark(s)	CWT + MM	MM+ Otolith A	Otolith B
Number	200,000	4,800,000	1,000,000

For comparison, a CWT-based DIT system would look like this:

Group	MCWT	M	UCWT
Mark(s)	CWT A +MM	MM	CWT B
Number	200,000	5,600,000	200,000

[5] Although a single otolith mark could be employed for chinook, the cumulative error with such an approach could be substantial. Therefore, only the SIT plus DIT-otolith system is described here.

[6] The SIT+ method could be implemented using only a single otolith mark as with coho. However, this approach could result in inconsistencies over time if process error results in different exploitation and escapement rates of the M and MCWT groups.

Age 2

Estimate the Age 2 cohort size prior to fishing for ***M*** and ***U*** from the Cohort Analysis (CA) of recoveries from the ***MCWT*** group:

The estimated survival rate to age 2 is determined through cohort analysis on the ***MCWT*** group. Assume that all release groups survive at the same rate:

$$s_2 = \frac{N_{MCWT,2}}{RS_{MCWT}} \qquad \text{(eq ch-1)}$$

$$N_{M,2} = s_2 * R_M$$

$$N_{U,2} = s_2 * R_U$$

The ratio between the two otolith marks at age 2 is thus

$$\lambda_2 = \frac{N_{U,2}}{N_{M,2}} = \frac{R_U}{R_M} \qquad \text{(eq ch-2)}$$

Exploitation rates for the M group. If the escapement rates for the ***M*** and ***MCWT*** groups are identical, assume that the exploitation rates are identical for all fisheries:

$$ER_{M,2,f} = ER_{MCWT,2,f} \qquad \text{(eq ch-3)}$$

If the escapement rates are not identical, adjust the fishery-specific exploitation rates for the difference. As with coho, there are a variety of methods that could be employed to make this adjustment. The simplest method would be to assume that the same bias is reflected in each fishery exploitation rate. With this method, first compute the escapement rates:

$$EscR_{MCWT,2} = \frac{Esc_{MCWT,2}}{N_{MCWT,2}} = (1 - PTER_{MCWT,2}) * MR_2 * (1 - THR_{MCWT,2})$$

$$EscR_{M,2} = \frac{Esc_{M,2}}{N_{M,2}} = (1 - \Delta * PTER_{MCWT,2}) * MR_2 * (1 - \Delta * THR_{MCWT,2}) \qquad \text{eq ch-3a}$$

The ratio between the two escapement rates is:

$$\frac{EscR_{M,2}}{EscR_{MCWT,2}} = \frac{(1 - \Delta * PTER_{MCWT,2}) * MR_2 * (1 - \Delta * THR_{MCWT,2})}{(1 - PTER_{MCWT,2}) * MR_2 * (1 - THR_{MCWT,2})} \qquad \text{eq ch-3b}$$

Rearranging, equation ch-3b becomes:

$$0 = \Delta^2 * (PTER_{MCWT,2} * THR_{MCWT,2}) - \Delta * (PTER_{MCWT,2} + THR_{MCWT,2}) + 1 - \frac{EscR_{M,2} * (1 - PTER_{MCWT,2}) * (1 - THR_{MCWT,2})}{EscR_M} \quad \text{eq ch-3c}$$

This is a quadratic equation with

$$a = (PTER_{MCWT,2} * THR_{MCWT,2})$$
$$b = -(PTER_{MCWT,2} + THR_{MCWT,2}) \quad \text{eq ch-3d}$$
$$c = 1 - \frac{EscR_{M,2} * (1 - PTER_{MCWT,2}) * (1 - THR_{MCWT,2})}{EscR_M}$$

Solving[7],

$$\Delta = \frac{-b - \sqrt{b^2 - 4ac}}{2a} \quad \text{eq ch-3e}$$

The fishery-specific exploitation rates for the M group are:

$$ER_{M,2,f} = \Delta * ER_{MCWT,2,f} \quad \text{(eq ch-3f)}$$

Exploitation rates for the *U* group:

Non-selective fisheries. Assume that the exploitation rates for ***U*** are identical to the exploitation rates for the ***M*** group.

$$ER_{U,2,f} = ER_{M,2,f} \quad \text{(eq ch-4)}$$

For mark-selective fisheries. Estimate the exploitation rate for ***U*** as follows.

Estimate the escapements of ***U*** ($ESC_{U,2}$) by reading otolith patterns at the hatchery (effects of straying are not included in this formulation, but adjustments could be incorporated to compensate). Note that these escapement estimates will include all impacts of fishery-related mortalities such as drop off, mark-retention, and mark-recognition error).

The escapement rate for the ***U*** group can be estimated from the sampling the otolith marked fish in the escapement.

$$EscR_{U,2} = \frac{ESC_{U,2}}{N_{U,2}} \quad \text{(eq ch-5)}$$

[7] In this case, the other potential solution is not feasible because it can produce exploitation rates that exceed 1.

In traditional cohort analysis, preterminal fisheries are computed as exploitation rates (i.e., the proportion of a cohort of a given age that is killed by a fishery) while terminal fisheries are computed as harvest rates (i.e., the proportion of mature fish of a given age that is killed by a fishery). In mathematical terms, the escapement of ***U*** is computed as:

$$ESC_{U,2} = N_{U,2} * (1 - PTER_{U,2}) * MR_2 * (1 - THR_{U,2}) \qquad \text{(eq ch-6)}$$

The PTERs and TERs can be further separated into their NSF and MSF components:

$$ESC_{U,2} = N_{U,2} * (1 - NPTER_{M,2} - MPTER_{U,2}) * MR_2 * (1 - NTHR_{M,2} - MTHR_{U,2}) \text{(eq ch-8)}$$

Estimation of fishery-specific exploitation rates using equation ch-8 is described for three cases: (1) MSFs occur only in terminal areas; (2) MSFs occur only in preterminal areas; and (3) MSFs occur in both terminal and preterminal areas.

Case 1 – MSFs only in Terminal Areas

Equation ch-8 becomes:

$$ESC_{U,2} = N_{U,2} * (1 - NPTER_{M,2}) * MR_2 * (1 - NTHR_{M,2} - MTHR_{U,2}) \qquad \text{(eq ch-8a)}$$

The escapement in the absence of MSFs is:

$$ESC^{N}_{U,2} = N_{U,2} * (1 - NPTER_{M,2}) * MR_2 * (1 - NTHR_{M,2}) \qquad \text{(eq ch-8b)}$$

So the cumulative incidental mortalities of U in MSFs is:

$$IM_{U,2} = Esc^{N}_{U,2} - Esc_{U,2} = N_{U,2}(1 - NPTER_{U,2}) * MR_2 * (MTHR_{U,2}) \qquad \text{(eq ch-8c)}$$

The total estimated incidental mortality using apriori assumptions of release mortality rates is:

$$CER_2 = \sum_{f \in msf} THR_{M,2,f} * sfm_f \qquad \text{(eq ch-8d)}$$

So the incidental mortality and fishery-specific exploitation rate for each MSF is:

$$IM_{U,2,f} = IM_{U,2} * \frac{THR_{M,2,f} * sfm_f}{CER_2} \qquad \text{(eq ch-8e)}$$

$$ER_{U,2,f} = \frac{IM_{U,2,f}}{N_{U,2}}$$

Example. A hatchery that produces 6,000,000 chinook smolts that are marked as indicated in the following table. Only non-selective fisheries are conducted in preterminal areas. IN terminal areas, two non-selective and two MSFs operate. Observable values are outlined and results of the cohort analysis on the MCWT group are depicted in the shaded cells:

	Cohort Analysis	MCWT	M + Otolith A	U + Otolith B
Released		200000	4,800,000	1,000,000
Survival to age 2	**0.10**	20000	480000	100000
Preterminal				
NSF 1	**0.10**	2000	48000	10000
NSF 2	**0.15**	3000	72000	15000
MSF 1	**0.00**	0	0	
Release Mortality Rate MSF1	**0.10**			0
MSF 2	**0.00**	0	0	
Release Mortality Rate MSF2	**0.10**			0
Maturation Rate	**0.05**			
Terminal Run		750	18000	3750
NSF 3	**0.10**	75	1800	375
NSF 4	**0.10**	75	1800	375
MSF 3	**0.10**	75	1800	
Release Mortality Rate MSF3	0.10			37.5
MSF 4	**0.10**	75	1800	
Release Mortality Rate MSF4	0.10			37.5
Escapement		450	10800	2925
Escapement no MSF				3000
Incidental Mortality				75

From cohort analysis of MCWT recoveries over all ages, the survival rate to age 2 is (0.10) and the age 2 maruration rate is (0.05).

Assuming that all groups survive at the same rate, the initial size of the surviving ***U*** group = 100,000 = 0.10*1,000,000 and the initial size of the surviving ***M*** group = 480,000 = 0.10*4,800,000.

The escapement rate for the U group in the absence of fishing = 0.03 =(1-0.10-0.15)*(0.05)*(1-0.10-0.10).

From equation ch-8b, the escapement for the ***U*** group in the absence of MSFs = 3000 =100,000*0.03.

From equation ch-8c, the incidental mortality of the ***U*** group due to MSFs = 75 = 3000-2925.

The fishery-specific exploitation rates of the U group in MSFs can now be computed using equations ch-8d-e.

Case 2 – MSFs only in Preterminal Areas

The number of fish remaining after preterminal fishing is:

$$PPTE_{U,2} = \frac{Esc_{U,2}}{MR_2 * (1 - NTHR_{M,2})} \quad \text{(eq ch-8f)}$$

In the absence of MSF, the number of fish remaining after preterminal fishing would be:

$$PPTE^{N}_{U,2} = N_{U,2} * (1 - NPTER_{U,2}) \quad \text{(eq ch-8g)}$$

So the incidental mortality loss of U in MSFs is:

$$IM_{U,2} = PPTE^{N}_{U,2} - PPTE_{U,2} = N_{U,2} * (1 - NPTER_{M,2}) - \frac{Esc_{U,2}}{MR_2 * (1 - NTHR_{M,2})} \quad \text{(eq ch-8h)}$$

The total estimated incidental mortality using apriori assumptions of release mortality rates is:

$$CER_2 = \sum_{f \in msf} PTER_{M,2,f} * sfm_f \quad \text{(eq ch-8i)}$$

The incidental mortality and exploitation rates for each MSF are:

$$IM_{U,2,f} = IM_{U,2} * \frac{PTER_{M,2,f} * sfm_f}{CER_2} \quad \text{(eq ch-8j)}$$

$$ER_{U,2,f} = \frac{IM_{U,2,f}}{N_{U,2}}$$

Example. A hatchery that produces 6,000,000 chinook smolts that are marked as indicated in the following table. Only non-selective fisheries are conducted in terminal areas. In preterminal areas, two non-selective and two MSFs operate. Observable values are outlined and results of the cohort analysis on the MCWT group are depicted in the shaded cells:

	Cohort Analysis	MCWT	M + Otolith A	U + Otolith B
Released		200000	4,800,000	1,000,000
Survival to age 2	**0.10**	20000	480000	100000
Preterminal				
NSF 1	**0.10**	2000	48000	10000
NSF 2	**0.15**	3000	72000	15000
MSF 1	**0.10**	2000	48000	
Release Mortality Rate MSF1	**0.10**			1000
MSF 2	**0.10**	2000	48000	
Release Mortality Rate MSF2	**0.10**			1000
Maturation Rate	**0.05**			
Terminal Run		550	13200	3650
NSF 3	**0.10**	55	1320	365
NSF 4	**0.10**	55	1320	365
MSF 3	**0.00**	0	0	
Release Mortality Rate MSF3	0.10			0
MSF 4	**0.00**	0	0	
Release Mortality Rate MSF4	0.10			0
Escapement		440	10560	2920
Fish remaining after preterminal fishing				73000
Fish remaining after preterminal fishing with No MSF				75000
Incidental Mortality Loss				2000

From equation ch-8f, the number of U fish remaining after preterminal fisheries = 73,000 = 2925/(0.05*(1-0.10-0.10)).

From equation ch-8g, the number of fish that would have remained after preterminal fishing in the absence of MSFs = 75,000 = 100,000*(1-0.01-0.15)).

From equation ch-8h, the incidental mortality of the ***U*** group in MSFs = 2000 = 75,000-73,000.

Fishery-specific exploitation rates are computed using equations ch-8i-j.

Case 3 – MSFs in both preterminal and terminal areas

In this instance, the estimation procedure would involve an apriori assumption that the estimates of terminal harvest rates for the marked fish and the release mortality in terminal MSFs are more reliable than for preterminal MSFs. First, estimate the terminal run size that results in the escapement of the ***U*** group:

$$TR_{U,2} = \frac{Esc_{U,2}}{(1 - NTHR_{M,2} - \sum_{f \in msf} THR_{M,2} * sfm_f)} \qquad \text{(eq ch-9a)}$$

Next, compute the escapement that would be expected in the absence of terminal MSFs:

$$Esc^N_{U,2} = TR_{U,2} * (1 - NTHR_M) \qquad \text{(eq ch-9b)}$$

The incidental mortality of the U group in terminal MSFs is then the difference:

$$IM_{U,2} = Esc^N_{U,2} - Esc_{U,2} \qquad \text{(eq ch-9c)}$$

The exploitation rates for the terminal MSFs can then be computed using equations ch-8d-e.

For the preterminal component, first compute the inferred number of fish remaining after preterminal fisheries:

$$PPTF_{U,2} = \frac{TR_{U,2}}{MR_2} \qquad \text{(eq ch-9d)}$$

Then compute the number of fish remaining after preterminal fisheries with no preterminal MSFs:

$$PPTF^N_{U,2} = N_{U,2} * (1 - NPTER_{M,2}) \qquad \text{(eq ch-9e)}$$

The incidental mortality of the U group in preterminal MSFS is then:

$$IM_{U,2} = PPTF^N_{U,2} - PPTF_{U,2} \qquad \text{(eq ch-9f)}$$

This is then allocated using equations ch-8h-j.

Example. A hatchery that produces 6,000,000 chinook smolts that are marked as indicated in the following table. In both preterminal and terminal areas, two non-selective and two MSFs operate. Observable values are outlined and results of the cohort analysis on the MCWT group are depicted in the shaded cells:

	Cohort Analysis	MCWT	M + Otolith A	U + Otolith B
Released		200000	4,800,000	1,000,000
Survival to age 2	**0.10**	20000	480000	100000
Preterminal				
NSF 1	**0.10**	2000	48000	10000
NSF 2	**0.15**	3000	72000	15000
MSF 1	**0.10**	2000	48000	
Release Mortality Rate MSF1	**0.10**			1000
MSF 2	**0.10**	2000	48000	
Release Mortality Rate MSF2	**0.10**			1000
Maturation Rate	**0.05**			
Terminal Run		550	13200	3650
NSF 3	**0.10**	55	1320	365
NSF 4	**0.10**	55	1320	365
MSF 3	**0.10**	55	1320	
Release Mortality Rate MSF3	0.10			36.5
MSF 4	**0.10**	55	1320	
Release Mortality Rate MSF4	0.10			36.5
Escapement		330	7920	2847
Terminal Run (apriori)				3650
Escapement no MSF				2920
Incidental Mortality Loss Terminal				73
After Preterminal Fisheries (with MSF)				73000
After PreTerminal Fisheries (No MSF)				75000
Incidental Mortality Loss PreTerminal				2000
Total Incidental Mortality Loss				2073

From equation ch-9a, the terminal run size of the ***U*** group = 3650 = 2847/(1-0.10-0.10-0.10*0.10-0.10*0.10).

From equation ch-9b, the escapement that would have occurred in the absence of terminal MSFs = 2920 =3650*(1-0.10-0.10).

From equation ch-9c, the incidental mortality due to MSFs in terminal areas = 73 =2920-2847. Exploitation rates in MSFs are then computed using equations ch-8d-e.

From equation ch-9d, the number of U fish remaining after preterminal fisheries = 73,000 = 3650/0.05.

From equation ch-9e, the number of U fish that would have remained in the absence of preterminal MSFs = 75,000 = 100,000*(1-0.10-0.15).

From equation ch-9f, the incidental mortality loss from MSFs in preterminal areas = 2000 =75,000-73,000.

Age 3+

Calculations for age 3 and older fish are similar to those for age 2 fish, except that the beginning cohort size is based on the maturation rates (***MR***) from the ***MCWT***-based CA. This procedure adjusts for the cumulative effects of differential MSF mortality and natural mortality.

The first step involves the separation of preterminal and terminal fishery impacts in order to account for the effect of maturation rates. The terminal run sizes of otolith marked groups ***M*** and ***U*** can be readily computed as:

$$TR_{M,2} = N_{M,2} * (1 - PTER_{M,2}) * MR_2 \qquad \text{(eq ch-10)}$$

$$TR_{U,2} = N_{U,2} * (1 - PTER_{U,2}) * MR_2$$

Assuming that there is no differential non-fishing mortality affecting the ***MCWT***, ***M*** and ***U*** groups, the age 3 pre-fishery cohort sizes for groups ***M*** and ***U*** can be computed as (note –in the cohort analysis methods employed by the PSC Chinook Technical Committee the survival rates after the first year of ocean residence are assumed known):

$$N_{M,3} = s_3 * TR_{M,2} * \frac{(1 - MR_2)}{MR_2} \qquad \text{(eq ch-11)}$$

$$N_{U,3} = s_3 * TR_{U,2} * \frac{(1 - MR_2)}{MR_2}$$

The unmarked:marked ratio, λ_3, is now equivalent to the mark ratios in the terminal runs at age 2. When MSFs impact age 2 fish in preterminal areas, the unmarked:marked ratio will differ from the initial release ratio (λ_2).

Exploitation rates for Age 3 ***M*** and ***U*** can be computed using equations analogous to eqs ch3-9. by simply replacing the subscripts *2* with 3.

For fish of age ***a***, stock-age-fisher exploitation rates would be estimated using the same formulas with 3 replaced by ***a*** and 2 by ***a-1***.

Further Investigations Needed

An in-depth analysis should be undertaken to evaluate the performance of SIT+, against CWT-DIT as a means of estimating exploitation rates of unmarked fish in MSFs.

Preliminary investigations using Monte Carlo simulation methods have yielded some insight into the uncertainty associated with DIT-based methods. Under DIT, the primary assumption is that the ***DIT-U*** and ***DIT-M*** groups will be encountered at the same rates in a MSF. Suppose that the same numbers of fish are released in the ***DIT-U*** and ***DIT-M*** groups. The encounter rates of the two groups should be 1:1. However, the probability that the ***DIT-U:DIT-M*** encounter ratio will deviate from 1:1 increases as the intensity of the MSF (the proportion of the marked fish that is targeted for harvest) decreases. There is considerable uncertainty that the DIT groups will be encountered at the same rates at low levels of MSF intensity. For instance, with releases of 30,000 fish in each DIT group, a 10% survival rate to recruitment, and a MSF harvesting 10% of the marked fish, the simulated encounters are depicted in Figure F1. Under the assumptions relied upon by DIT methods, 30 fish from each of the DIT groups should be encountered. The scatter about this point indicates that the validity of this assumption is questionable; although the encounters tend to center about the expectation, considerable variability would be expected about the encounters of the two DIT groups in a single experiment.

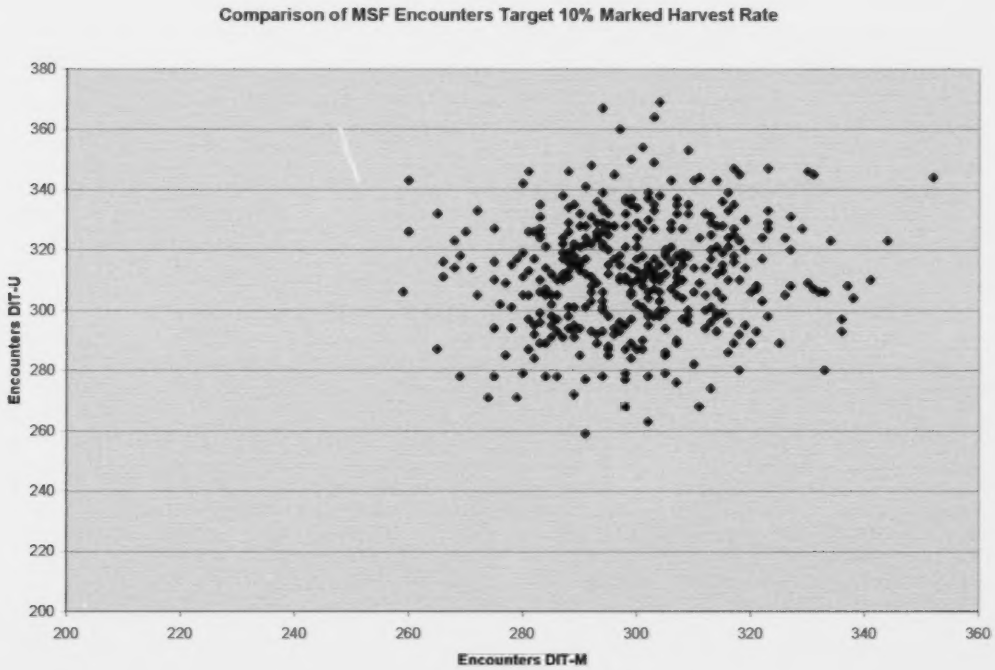


Figure F1. Simulated encounters of DIT-U and DIT-M fish

Further, the scatter in Figure F1 indicates a tendency to underestimate the encounters of the ***DIT-U*** group; this bias is likely due to the structure of the simulation model (the DIT approach assumes that all fish are encountered instantaneously while the model removes ***DIT-M*** fish as the

MSF proceeds – since ***DIT-M*** fish are removed faster than the *DIT-U* fish, the probability of encountering ***DIT-U*** fish increases over time while the probability of encountering a ***DIT-M*** decreases). As the intensity of the MSF increases, bias becomes more apparent (Figure F2).

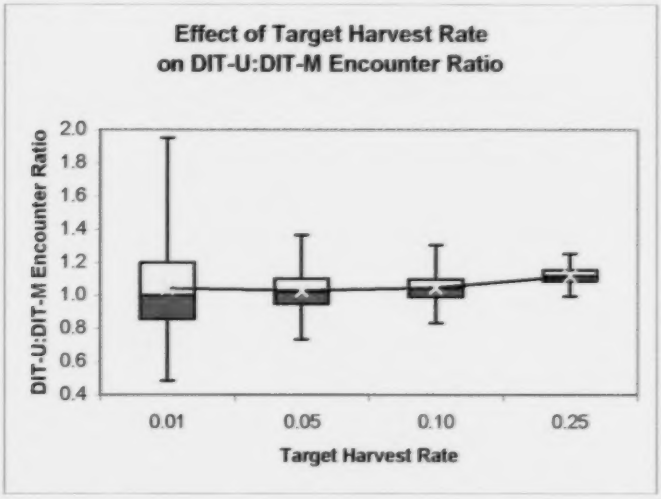


Figure F2. Box and whiskers plot of encounter ratios of DIT-U:DIT-M fish at various target harvest rates for removal of DIT-M fish.

The performance of SIT+ and DIT should be initially investigated using simulation methods, focusing on comparing expected uncertainty (precision and bias) under a variety of MSF scenarios. The analysis should include including investigation of alternative algorithms for allocating mortalities among multiple MSFs and the potential to reduce uncertainty in estimates of fishery-specific exploitation rates of CWT-releases by increasing release group sizes. If the performance of SIT+ appears sufficiently promising, a detailed pro-forma comparison of the relative making and sampling costs of implementation for SIT+ and DIT should be completed. Pilot studies should be undertaken before full scale implementation is attempted.

Notation

Δ	Scalar to adjust for differences between observed escapement rates of the MCWT and M groups
λ_a	Unmarked:Marked ratio for age *a* fish
CER_a	Total apriori assumed incidental (release) mortality of age a *U* fish.
$ER_{g,a,f}$	Exploitation rate for fish of age *a* fish in fishery *f* for group *g*
$ESC_{g,a}$	Escapement of age *a* fish from group *g*
$ESC^{N}_{g,a}$	Escapement of age *a* fish from group *g* in the absence of MSFs
$EscR_{g,a}$	Escapement rates of otolith marked age *a* fish from group *g*
$IM_{U,a,f}$	Incidental mortality of age *a* unmarked fish in MSF *f*
M	Fish with otolith mark A
MER_M	Cumulative exploitation rate of M fish in MSFs
$MPTER_{g,a}$	Preterminal Exploitation Rate for group *g* age *a* fish in MSFs
MR_a	Maturation rate for MCWT fish of age *a*
MSF (msf)	Mark-selective fishery
$MSFER_{g,a}$	Exploitation Rate for group *g* age *a* fish in MSFs
$MTER_{g,a}$	Harvest Rate for group *g* age *a* fish in MSFs in terminal areas, expressed as an exploitation rate
$MTHR_{g,a}$	Harvest Rate for group *g* age *a* fish in MSFs in terminal areas
$N_{g,a}$	Cohort size of age *a* group *g* fish prior to fishing
$NPTER_{g,a}$	Preterminal Exploitation Rate for group *g* age *a* fish in NSFs
NSF (nsf)	Non-Selective fishery
$NTER_{g,a}$	Harvest Rate for group *g* age *a* fish in MSFs in terminal areas, expressed as an exploitation rate
$NTHR_{g,a}$	Harvest Rate for group *g* age *a* fish in NSFs in terminal areas
$PPTF_{U,a}$	Post preterminal fishery cohort size of age *a*, *U* group (number of fish remaining after preterminal fisheries)
$PPTF^{N}_{U,a}$	Post preterminal fishery cohort size of age *a*, *U* group (number of fish remaining after preterminal fisheries) in the absence of MSFs
$PTER_{g,a}$	Preterminal Exploitation Rate for group *g* age *a* fish
R_g	Release size of fish group g
RS_g	Release size of fish with otolith mark group g
$sfm_{a,f}$	Release mortality for age *a* fish in fishery *f*
$TER_{g,a}$	Terminal harvest Rate for group *g* age *a* fish, expressed as an exploitation rate
$THR_{g,a}$	Terminal harvest Rate for group *g* age *a* fish
$TR_{g,a}$	Terminal Run size of age *a* fish from group *g*
U	Unmarked fish with otolith mark

APPENDIX G. Increasing Fishery Complexity Leads to Increased Uncertainty in Estimated Fishery-Specific Exploitation Rates.

As discussed in the section on the "Increasing Complexity of Fisheries" in Part I above, over the course of the last two decades, the PSC and fishery managers have sought to obtain information at finer and finer scales of fishery-time resolution to address conservation concerns for individual stocks. However, as strata become more refined, the uncertainty surrounding estimates of exploitation rates increases. The increased uncertainty associated with the estimates that can be provided through the CWT system can be illustrated by examining three different versions of chinook models used by the PSC and Chinook Technical Committee. The first version that was used to determine allocation consisted of 10 fisheries and four stocks and an annual time step; the current version has 25 fisheries and 30 stocks with an annual time step and currently there are plans to increase the time-steps to four within a year, the fisheries to 70 or more and further increase the stocks.

In Table G1 the distribution of all fishery time-steps is shown for CWT recoveries of the Columbia River Upriver Bright stock for brood years 1975-1985 using the three different model configurations: (a) the 10 fishery model with an annual time step; (b) the current 25 fishery model with an annual time step, and (c) a 25 fishery model with four time steps per year. The total number of fishery-time steps, or resolution, increases with additional fisheries and time periods, from 672 to 1,310 and 5.210 time step strata for the three configurations. As the resolution increases, with more fisheries and then four time steps, the proportion of the fishery-time step strata with small fishery percent mortalities increases (Figure G1).

Figure G1 shows the distribution of the percent mortalities[8], including strata where no tags were recovered. The percent mortality in a fishery is used here as it is equivalent to an exploitation rate for the purposes of estimating variances and standard error, which measure uncertainty in the estimates. The period of 1975-1984 was chosen as these were years of large fisheries (extending over larger areas and longer time periods) and therefore higher exploitation rates and larger numbers of tag recoveries for the fishery-time step strata. Table G1 and Figure G1 show the distribution of fishery-time step strata, which have at least one tag recovered. For the 10 fishery model this is 52% of all strata, but increases to 68% for the current 25 fishery model and to 90% when four time steps are introduced. With further increase in fisheries this percentage of strata with no tag recoveries can be expected to increase.

The uncertainty of the estimate of mortalities and percent mortalities is a function of the number of CWTs observed in each fishery-time step stratum for the stock-age group. As the resolution becomes finer, the number of tags in an individual stratum will obviously decrease. Because fewer tags are present in each stratum, the precision of the estimate of exploitation rates is degraded and uncertainty increases. Uncertainty in the estimates of exploitation rates and

---

[8] Percent mortalities= $\frac{FisheryMortality}{TotalFisheryMortality}$

percent mortality is measured here by the percent standard error (PSE)[9], which is the size of the standard error relative to the estimate of percent mortality. This measure would be expected to increase as the number of strata increases and the number of CWTs recovered in each stratum decreases. In Figure G2 the distribution of the PSEs of the percent mortality shows a shift to the right, as a larger proportion of the fishery time strata have larger PSEs due to the decreasing number of recovered tags per stratum.

Table G1. Distribution of PSE for estimates of fishery distribution (mortality in fishery over total fishery mortalities) for Upriver Brights for three configuration of fishery-time steps used in CTC model for CWT data from 1975-1984.

	10 fishery model	25 fishery model	25 fisheries + Four Time Steps
No tags recovered	351	892	4,672
% of fishery-time steps	52%	68%	90%
PSE 0-10%	23	31	33
% of fishery-time steps	3%	2 %	1%
PSE 10-20%	51	45	46
% of fishery-time steps	8%	3 %	1%
PSE 20-30%	49	48	50
% of fishery-time steps	7%	4%	1%
PSE 30-40%	35	40	50
% of fishery-time steps	5%	3%	1%
PSE 40-50%	32	47	60
% of fishery-time steps	5%	4%	1%
PSE 50-60%	29	36	56
% of fishery-time steps	4%	3%	1%
PSE 60-70%	33	51	60
% of fishery-time steps	5%	4%	1%
PSE > 70%	69	120	183
% of fishery-time steps	10%	9%	3%
Total fishery-time steps	672	1,310	5,210

[9] Percent standard error (PSE) = $\frac{SE}{PercentMortality} * 100$

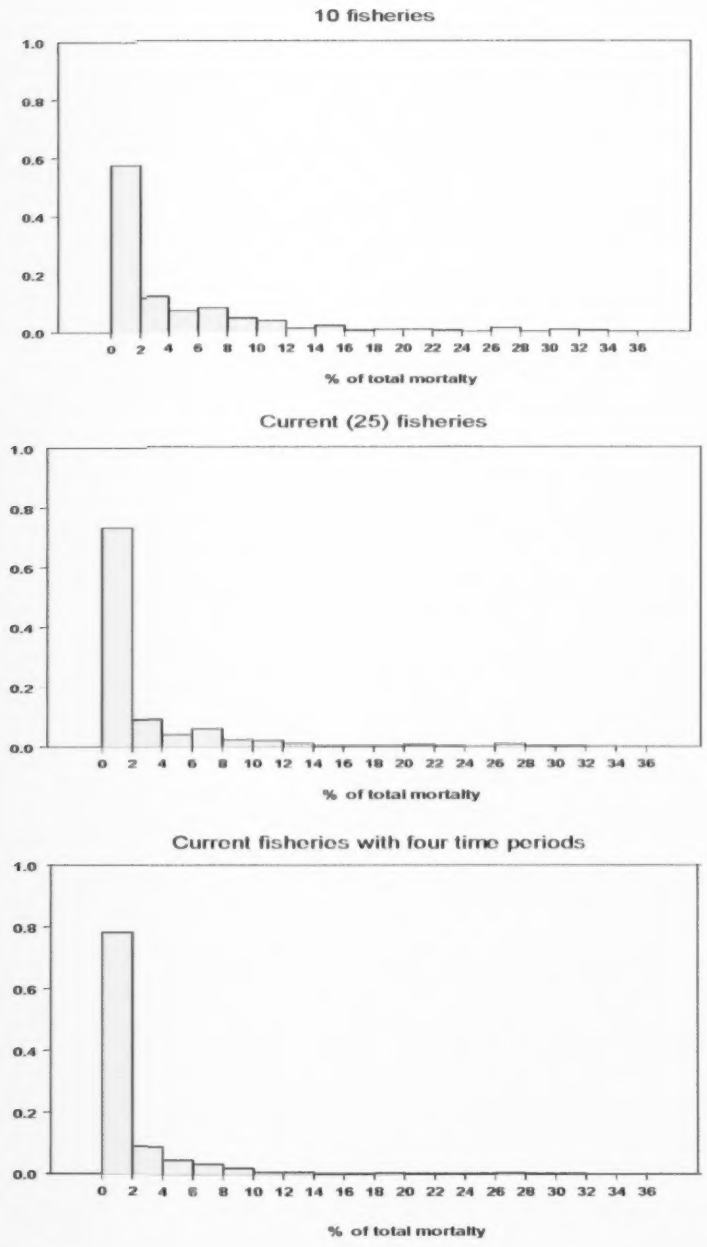


Figure G1. **Distribution of percent fishery mortalities for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) current or 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year.**

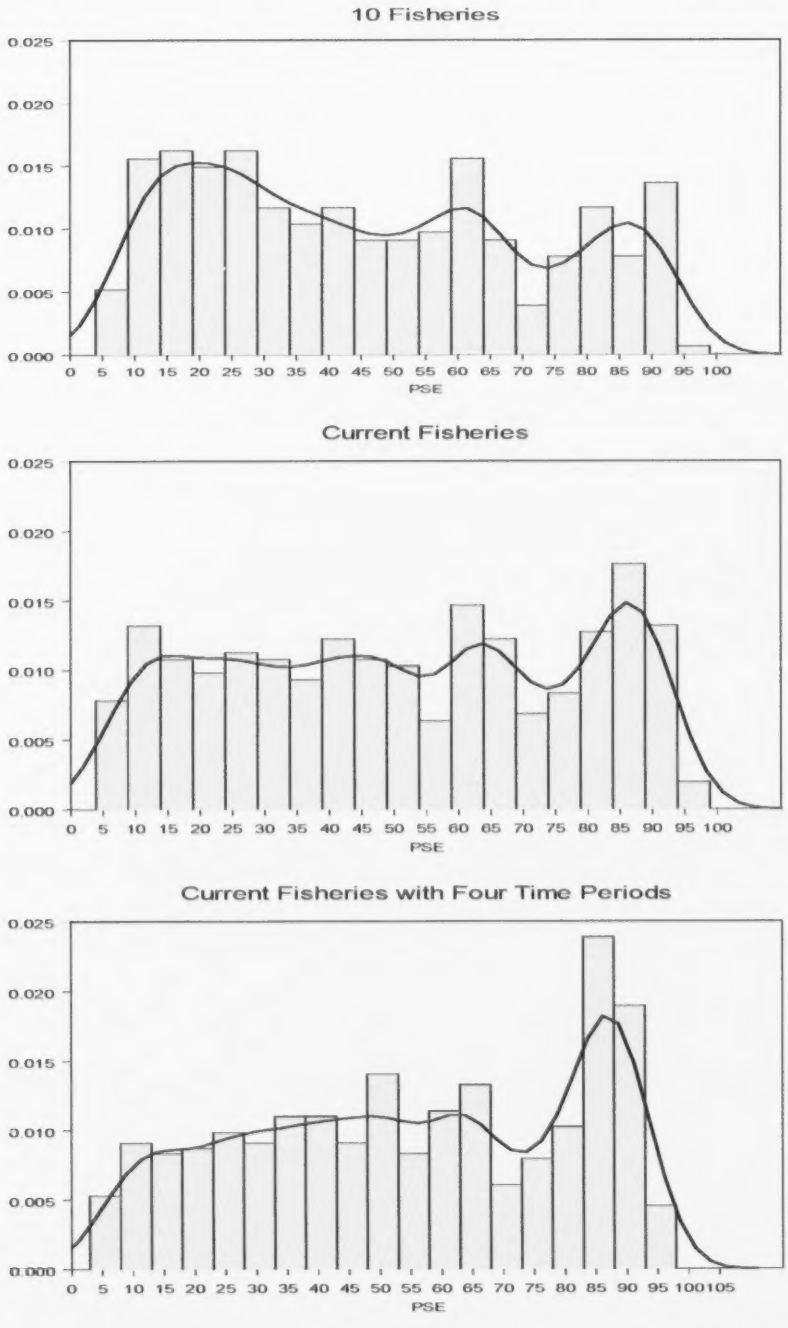


Figure G2. Distribution of percent standard error (PSE) for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year

For the brood years 1975-1985 the percent of the tagged release that was harvested in fisheries was at its highest, but since 1985, with increasing fishery restrictions, this percent has decreased (Figure G3). Thus the CWT data available for the later time period would be expected to be even sparser than in the fishery-time period configurations used above. Table G2 shows the distribution of the PSE for percent fishery mortality for the brood years 1989-1998. This illustrates how the uncertainty has increased for the three model configurations for this time period, with even the 10 fishery model having 72% of the fishery time-steps with no tags recovered at all. For the current 25 fishery model 84% of the strata have no recoveries and this increases to 95% if four time steps are included. With increasing resolution in the fishery-time steps the uncertainty can only increase.

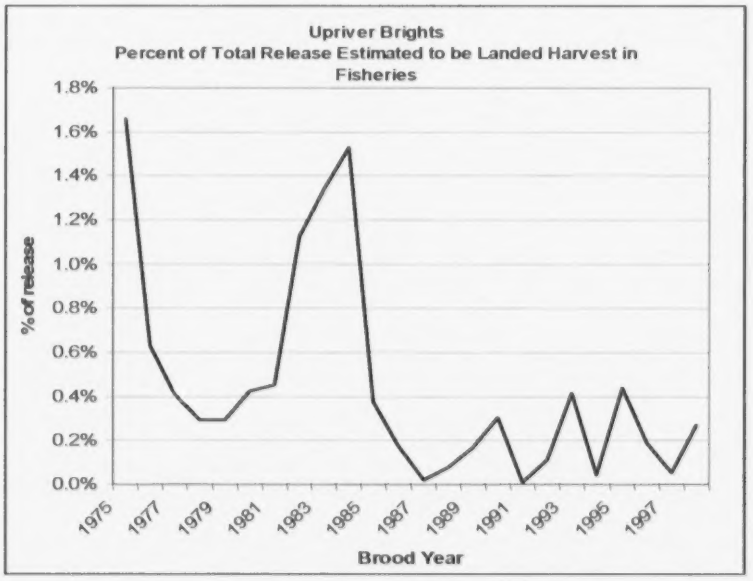


Figure G3. Percent of total tagged release that is estimated to be landed harvest in fisheries for brood years 1975-1998 for Upriver Bright chinook salmon.

Table G2. Distribution of PSE for estimates of fishery distribution (mortality in fishery over total fishery mortalities) for Upriver Brights for three configuration of fishery-time steps used in CTC model for CWT data from 1989-1998.

	10 fishery model	25 fishery model	25 fisheries + Four Time Steps
No tags recovered	402	1145	4952
% of fishery-time steps	72%	84%	95%
PSE 0-10%	4	4	7
% of fishery-time steps	1%	0%	0%
PSE 10-20%	26	28	25
% of fishery-time steps	5%	2%	0%
PSE 20-30%	23	27	31
% of fishery-time steps	4%	2%	1%
PSE 30-40%	20	27	23
% of fishery-time steps	4%	2%	0%
PSE 40-50%	18	20	36
% of fishery-time steps	3%	1%	1%
PSE 50-60%	17	20	22
% of fishery-time steps	3%	1%	0%
PSE 60-70%	12	21	26
% of fishery-time steps	2%	2%	1%
PSE > 70%	38	68	96
% of fishery-time steps	7%	5%	2%
Total fishery-time steps	560	1360	5210

The relationship between the precision or PSE for the estimates of percent mortality and the number of tags recovered in a fishery-time step is shown in Figure G4. The rate of decline in the PSE gets smaller as the number of tags increases. Examination of the Figure G4 shows that the PSE does not fall below 30% until the number of tags in a fishery-time period strata is higher than 10.

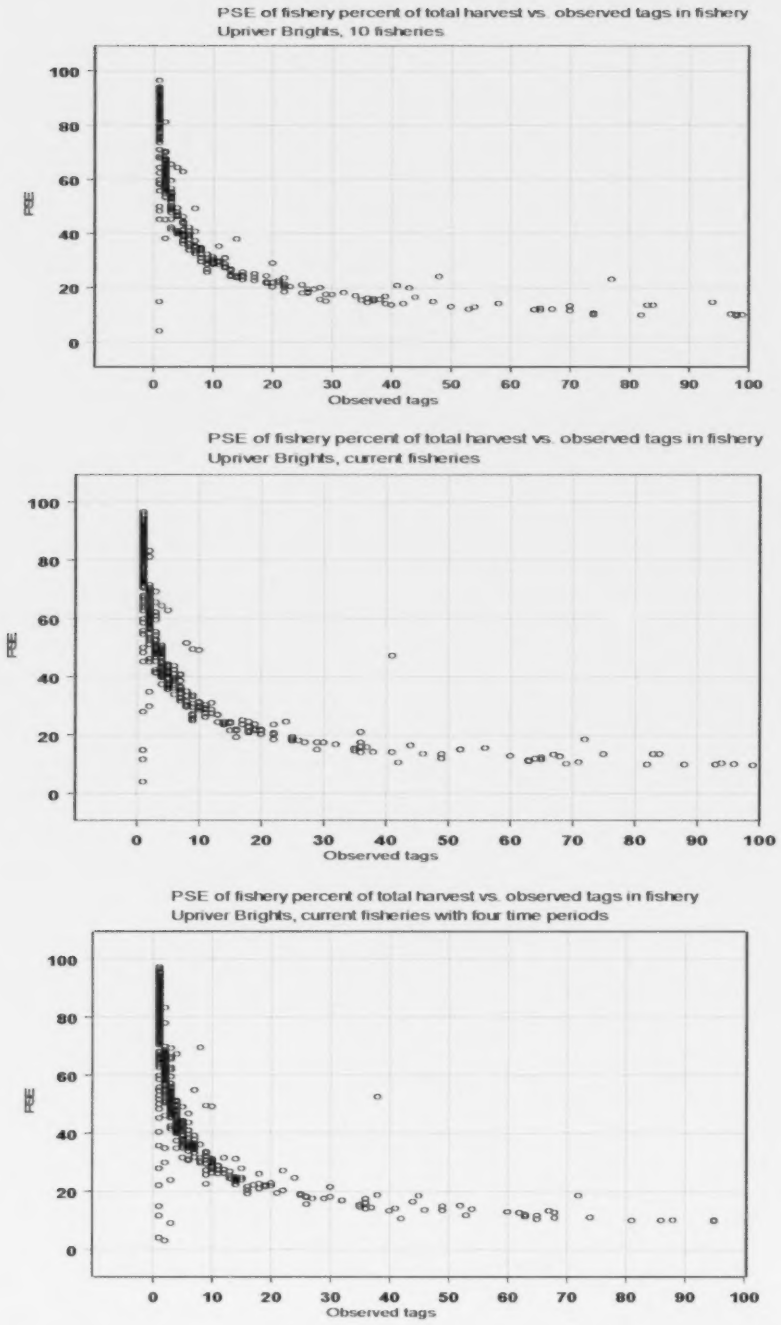

PSE of fishery percent of total harvest vs. observed tags in fishery
Upriver Brights, 10 fisheries
PSE
Observed tags
PSE of fishery percent of total harvest vs. observed tags in fishery
Upriver Brights, current fisheries
PSE
Observed tags
PSE of fishery percent of total harvest vs. observed tags in fishery
Upriver Brights, current fisheries with four time periods
PSE
Observed tags

Figure G4. Distribution of percent standard error (PSE) vs number of tagged recoveries for fishery percent of total for Columbia River Upriver Brights with fisheries and time periods in three configurations: (a) 10 fisheries; (b) 25 fisheries and an annual time step; and (c) 25 fisheries and four periods per year.

Table G3 shows the percent of the fishery-time period strata that have 10 or more tags. For the early period (broods 1975-1984) this is 22% of all strata, including strata with no tags recovered. This decreases to 14% for the current 25 fishery model and to 3% when four time-steps are included. When the same summary is done for the 1989-1998 broods, only 9% of the 10 fishery – annual time step strata have over 10 tags recovered, and for the current 25 fishery with four time steps only 1% of the strata have over 10 tags, 95% have no tags.

Table G3. Number and percent of fishery-time step strata with 0, 10 or fewer and more than 10 tags recovered for Upriver Brights for two groups of broods, 1975-1984 and 1989-1998.

Tags Recovered		1975-1984 broods			1989-1998 broods		
		10 fishery model	25 fishery model	25 fisheries + Four Time Steps	10 fishery model	25 fishery model	25 fisheries + Four Time Steps
No tags	No. Fishery – Time Steps	351	892	4,672	399	1141	4940
	% of total	52%	68%	90%	71%	84%	95%
<10 tags	No. Fishery – Time Steps	176	233	385	113	168	122
	% of total	26%	18%	7%	20%	12%	2%
>10 tags	No. Fishery – Time Steps	145	185	153	48	51	49
	% of total	22%	14%	3%	9%	4%	1%
	Total Fishery - Time steps	672	1310	5210	560	1360	5210

Table G3 illustrates that while finer resolution in fishery-time strata can increase uncertainty, there are other factors that will have similar results. Without increasing sampling rates or tagging levels, reductions in fishery harvest rates or survival rates will similarly reduce the number of CWTs recovered and increase uncertainty for each fishery-time stratum.

It is important for fishery managers to recognize that the uncertainty of CWT-based estimates of exploitation rates increases as the number of CWTs recovered in a given strata of interest decreases. Given that levels of survival and harvest rates will not increase in future, the number of tags recovered in a fishery-time step depends on the sampling and tagging levels. In order to use CWT in fishery models such as the CTC model, criteria should be developed for the precision and accuracy of the exploitation rates and other statistics to be estimated and tagging and sampling levels set accordingly (see Recommendations 2 and 3).

In addition, fishery managers should recognize that with increasing uncertainty in these fishery management measures there will be greater uncertainty in attaining management objectives and these should be adjusted to compensate, (see Recommendation 6).

APPENDIX H. Comparison of Sampling Requirements for CWT and Genetic Based Methods.[10]

Context.

The principal focus of the PSC's management regimes for chinook and coho salmon is directed at conservation of individual natural stocks. These regimes are currently monitored and evaluated using cohort analysis methods on recovery data for individual CWT release groups from hatcheries which are selected to be representative of natural stocks. The CWTs provide unequivocal information regarding the origin and age of individual fish as well as information on location and timing of recovery; all of which are required to generate stock-age-fishery specific exploitation rates (SAF-ERs, see Morishima and Alexandersdottir 2004).

The emergence of microsatellite-DNA methods (GBM) in recent years has prompted some to conjecture that the PSC's objectives for management of natural stocks of chinook and coho salmon can be met at lower costs using GBM systems compared to continued reliance on the current CWT system. This appendix compares sample size requirements of GBM and CWT-based systems for providing data required to estimate SAF-ERs.

Estimate stock composition.

GBM is intended to generate estimates of stock composition, not data needed for cohort analysis and estimation of SAF-ERs. In theory, it would be possible to use GBM-based stock compositions coupled with other information on ages of individual fish to provide data required for implementation of the PSC current management regimes for chinook and coho if the necessary level of resolution can be provided. In order to provide that level of resolution, individual fish must be correctly assigned to individual release groups by stock and age. Then, the contributions of individual populations of interest could be estimated simply by multiplying stock compositions by the catch sample size.

Statistically, the capacity of a GMB system to accurately estimate the contribution of an individual stock improves as the proportion of the stock in fishery increases. For a given sample size, the contribution of major contributing stocks can be estimated better than the minor contributing stocks. However, when sampling is conducted at levels sufficient to estimate stock-age impacts, the costs of GBM sampling are likely to be far higher than under the CWT system.

[10] Gary S. Morishima and M. Alexandersdottir.

Consider the following example. A catch sample of 5,615 fish contains equal numbers of recoveries of three CWT'd groups which are used to represent untagged populations (stocks) of various sizes.

STOCK A		STOCK B		STOCK C		OTHER	
CWT 1	Untagged fish from release	CWT 2	Untagged fish from release	CWT 2	Untagged fish from release	CWT Other	Unknown Origin
5	0	5	500	5	5000	0	100

The number of fish from different component stocks group in a sub-sample of the catch sample has a multivariate hyper-geometric distribution. The probability of detecting the correct stock composition of the catch sample by sub-sampling depends on the specific details of the stock composition. The likelihood that these proportions will be correctly estimated depends upon the proportion of the catch sample that is processed for genetic ID.

In the above example, when a visual cue is used to unambiguously indicate the presence of a CWT, only 15 fish must be processed. These data can be extracted (presumably without error as to release group and age) by processing the same number of fish, regardless of the size of the stock of interest. The CWT recoveries from processing 15 fish would provide the data required to support cohort analysis and estimate SAF-ERs for this fishery.

In contrast, under a GBM approach, it would be necessary to correctly estimate all the proportions of stocks A-C simultaneously to extract equivalent information on the stocks present in the catch sample. The stock-specific information contained in the catch sample can only be recovered with certainty by processing the entire sample of 5,615 fish even assuming no error in stock assignment. Because current stock composition estimation algorithms assign every fish to a particular stock group contained in a given baseline, errors in stock assignment may occur. Additionally, the ability of GBM to associate individual fish to specific populations can be difficult because many populations of hatchery and natural stocks share a common genetic origin.

A simple example can illustrate potential impacts of error in assigning individual fish to their correct stocks. The assignment errors employed in the example are extreme for illustrative purposes, but the effect on bias remains unchanged. The model draws random sub-samples of various sizes to estimate the stock composition of the entire catch sample. The probability that the stock proportions would be correctly estimated within a relative error {(est-true)/true}of 5% is depicted in the table below.

Sub-Sample Size	P(all stock proportions within tolerance)	P(Stock A proportion within tolerance)	P(Stock B proportion within tolerance)	P(Stock C proportion within tolerance)	P(Stock D proportion within tolerance)
100	0.00	0.00	0.12	0.87	0.00
500	0.00	0.00	0.34	1.00	0.16
1000	0.00	0.00	0.44	1.00	0.21
3500	0.13	0.34	0.89	1.00	0.46
5600	0.99	0.99	1.00	1.00	1.00

Bias and uncertainty arise when individual fish cannot be assigned to specific stocks without error. Under commonly employed GBM assignment methods, all fish are assigned to the stock with the highest probability of being correct, and stock compositions are estimated as proportions. Therefore, assignment error in one stock can affect estimated stock contributions of other stocks.

The magnitude of the problem will be affected by the relative error in the capacity to correctly assign individual fish to specific populations and composition of the catch. To illustrate, consider a situation where four stocks comprise substantially different proportions of the catch and where the ability to correctly assigning individual fish to specific populations is described by a simple conditional probability distribution as depicted in Table H1. The impact of assignment error can be illustrated by the results of a Monte-Carlo model that simulates the assignment of individual fish 500 times. The relative bias[11] in the estimates of total by stock contributions ranges from 4 to -3040%. This is the error that would result if every fish in the catch sample in the example were processed with this assignment error. The bias is a function of the relative size of the mixture of stocks, the large bias for stocks 1 and 2 is due to the assignment error of stocks 3 and 4, which are much larger in the example. The Monte-Carlo model can also be used to evaluate the bias and uncertainty surrounding estimates of stock contributions resulting from sub-sampling. When there is no stock assignment error, there would be no expected bias at any sample size (Figure H1); sub-sampling would produce random error, but not systematic bias.

Table H1. Allocation to stock using assignment matrix used in simulation and calculation of error and estimated relative bias in percent due to misallocation to stock.

Stock	True Number	Assigned to Stock 1	Stock 2	Stock 3	Stock 4
1	60	54	3	3	-
2	600	30	540	30	-
3	60,000	1,200	1,200	57,000	600
4	6,000	600	600	600	4,200
Total estimated by stock =		1,884	2,343	57,633	4,800
Bias in total by stock		1,824	1,743	-2,367	-1,200
% Relative Bias		3040%	291%	-4%	-20%
Assignment Matrix used:		**Stock 1**	**Stock 2**	**Stock 3**	**Stock 4**
Stock 1 assignment to stock by %		90%	5%	5%	0%
Stock 2 assignment to stock by %		5%	90%	5%	0%
Stock 3 assignment to stock by %		2%	2%	95%	1%
Stock 4 assignment to stock by %		10%	10%	10%	70%

[11] Relative Bias $\left[= \frac{Estimate - True}{True} \right] \cdot 100.$

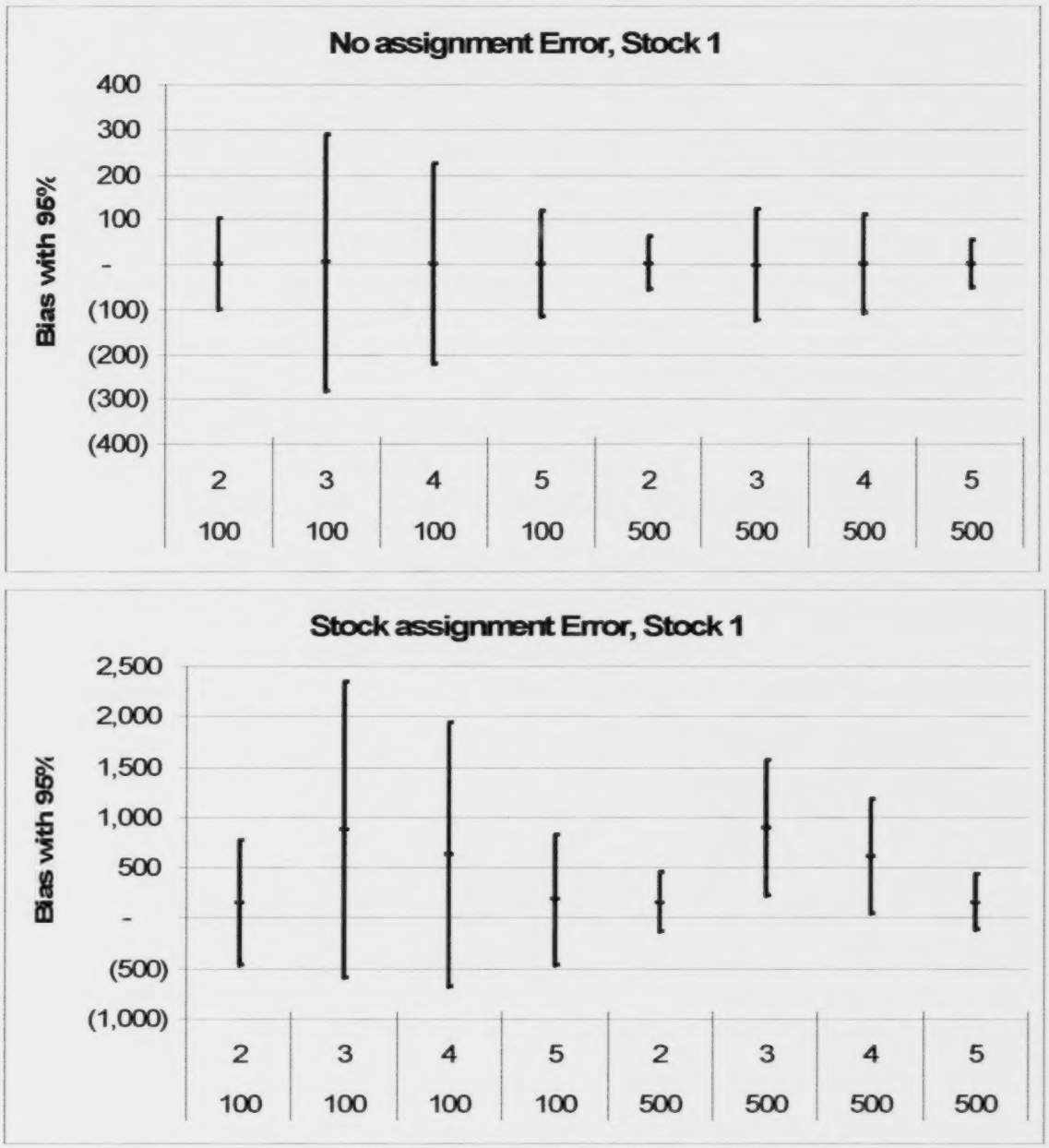


Figure H1. **Average of error in 500 simulations (=bias) with 95% confidence interval for stock 1 with and without assignment error.**

This simple example illustrates two important concepts for estimating the impact of a fishery on stocks of interest: (1) the ability of GBM sub-sampling to correctly identify the contribution of an individual stock depends upon the proportion of the total catch sample that is comprised of that stock and the degree of uncertainty involved in the assignment of individual fish to the correct population; (2) error in GBM sub-sampling in one stock biases the estimate of contribution of other stocks. The number of fish that must be sampled depends upon prior knowledge of the stock composition. Without processing all the fish in the sample so that the stock composition is known, the uncertainty in stock composition estimates from GBM sub-sampling cannot be known, even with no error in assignment of individual fish to their correct populations. Multiple sub-samples could be employed to provide information on the variability of the stock composition estimates, but with small sample sizes, considerable uncertainty would still remain when complex stock mixtures are involved. In this simple example, the probability of any single sub-sample of modest size detecting the correct stock composition of the entire catch sample would be very small. The stock compositions resulting from a small sub-sample drawn from a highly mixed stock fishery in any real life situation are likely to be extremely uncertain.

Aging.

When the catch sample contains fish of different ages, the estimation problem becomes even more complex because individual fish must be associated with discrete populations and ages simultaneously. Bias and uncertainty arise when individual fish cannot be assigned to specific stocks and ages without error.

Table H2 shows the results of a Monte-Carlo simulation involving sample sizes of 100 to 500. On the left hand side, the table shows the true value for each stock and age and scenario, the estimated value and the standard deviation of the 500 simulations. On the right hand side the hypothesis was tested that the average error (Estimate – True) of the 500 estimated values was equal to zero. A significant test would indicate significant bias in the estimates, i.e. a 95% confidence interval would not include zero (Table H2). When there is no assignment error, none of the tests are significant, low Z-statistics and high p-values (Table H2).

When error is involved in stock-age assignments, as the sample size increases the number of significant tests increase. For small sample sizes, the imprecision due to sample variability (i.e., the SD of the 500 simulations) is too large to detect the bias. But at larger sample sizes, the bias is detected. For stock 1 for instance, Figure H1 shows the 95% confidence interval of the estimated bias (Estimate – True) for the 500 simulations, which show large over-estimations of stock contributions (Table H1). However, except for ages 3 and 4 at a sample size of 500, all of the confidences intervals include zero, i.e., large imprecision swamps the bias.

Assignment error will lead to bias. The level of bias is dependent on the mix of stocks and the accuracy of assigning them and the relative sizes of the stocks. If the capacity to accurately assign individual fish to a population is a function of baseline samples, standards are needed to determine the sample size for each population in the baseline, the differences between populations and the coverage (i.e., how many unknown stocks present).

Conclusion.

GBM methods could provide useful information to help validate certain assumptions such as the degree to which CWT indicator stocks represent their associated natural populations and for providing information, such as the ability to determine the contribution of major stock groups to the population of sub legal sized fish encountered in a fishery through non-lethal means.

However, sampling costs of GBM approaches are likely to be far higher than those incurred under the CWT system. When the purpose of the sampling is to estimate SAF-ERs, particularly for stocks that comprise a relatively small proportion of the fished population, the number of fish that must be processed to obtain the data required to estimate SAF-ERs at required levels of resolution is likely to be far higher under GBM than under the CWT system. It is extremely unlikely that GBM methods would be capable of providing the data necessary to reconstruct cohorts at costs lower than the CWT system just due to sampling costs alone.

When comparable numbers of fish are processed to extract stock and age data, the uncertainty surrounding the accuracy of data derived from GBM will be much larger than for a CWT-based method. When results are combined for many strata, the uncertainty surrounding estimates of SAF-ERs produced through cohort analysis based on small GBM sample sizes, uncertainty in the management system would substantially increase. Leaving aside issues of correct stock and age determination, unless very large samples of tissues are processed, the error in estimates of data required for cohort reconstruction and analysis to estimate SAF-ERs is likely to be very large.

Citation.

Morishima, G.S., and Alexandersdottir, M. 2004. Data matrix: requirements for assessment of fishery impacts on salmon stocks.

Table H2. Mean and SD for 500 iterations estimating number by stock and age for three scenarios and results of test of null hypothesis that there is no difference between the mean of the estimate and the true value.

Stock	Age		Mean and Standard Deviation of Iterations					Ho: No bias in estimates, i.e., Mean-True Value = 0.0					
			Sample Size						Sample Size				
			100	200	300	400	500		100	200	300	400	500
1	2	True Value	*5*	*5*	*5*	*5*	*5*						
		Mean, no assignment error	4	3	7	5	6	Z-statistic	0.02	0.08	0.04	0.00	0.03
		SD	52	30	40	28	30	p-value	0.98	0.94	0.97	1.00	0.98
		Mean, stock assignment error	147	152	157	147	159	Z-statistic	0.45	0.64	0.79	0.91	1.04
		SD	315	230	193	156	148	p-value	0.65	0.52	0.43	0.36	0.30
		Mean, stock and age assignment error	159	164	164	157	170	Z-statistic	0.48	0.67	0.82	0.97	1.08
		SD	322	238	194	157	153	p-value	0.63	0.50	0.41	0.33	0.28
	3	True Value	*30*	*30*	*30*	*30*	*30*						
		Mean, no assignment error	33	24	36	32	28	Z-statistic	0.02	0.07	0.06	0.02	0.03
		SD	145	89	87	73	64	p-value	0.98	0.95	0.95	0.98	0.97
		Mean, stock assignment error	907	939	942	952	923	Z-statistic	1.17	1.57	2.11	2.37	2.63
		SD	748	579	431	389	340	p-value	0.24	0.12	***0.04***	***0.02***	***0.01***
		Mean, stock and age assignment error	889	924	939	945	919	Z-statistic	1.16	1.60	2.13	2.37	2.64
		SD	738	558	427	387	337	p-value	0.24	0.11	***0.03***	***0.02***	***0.01***
	4	True Value	*20*	*20*	*20*	*20*	*20*						
		Mean, no assignment error	20	21	19	17	20	Z-statistic	0.00	0.01	0.01	0.05	0.01
		SD	114	80	67	55	56	p-value	1.00	0.99	0.99	0.96	1.00
		Mean, stock assignment error	641	619	632	621	625	Z-statistic	0.93	1.37	1.64	1.96	2.10
		SD	667	439	374	306	289	p-value	0.35	0.17	0.10	***0.05***	***0.04***
		Mean, stock and age assignment error	621	601	611	600	607	Z-statistic	0.91	1.29	1.60	1.87	2.00
		SD	662	450	370	309	293	p-value	0.36	0.20	0.11	0.06	***0.05***
	5	True Value	*5*	*5*	*5*	*5*	*5*						
		Mean, no assignment error	5	7	6	3	5	Z-statistic	0.01	0.05	0.02	0.07	0.01
		SD	59	49	35	23	26	p-value	1.00	0.96	0.98	0.94	0.99
		Mean, stock assignment error	183	147	159	160	156	Z-statistic	0.54	0.64	0.82	0.93	1.08
		SD	331	222	187	167	141	p-value	0.59	0.52	0.41	0.35	0.28
		Mean, stock and age assignment error	208	169	177	177	168	Z-statistic	0.59	0.70	0.85	0.97	1.11
		SD	342	232	204	178	147	p-value	0.55	0.48	0.40	0.33	0.27

Table H2. Mean and SD for 500 iterations estimating number by stock and age for three scenarios and results of test of null hypothesis that there is no difference between the mean of the estimate and the true value.

Stock	Age		Mean and Standard Deviation of Iterations					Ho: No bias in estimates, i.e., Mean-True Value = 0.0					
			Sample Size						Sample Size				
			100	200	300	400	500		100	200	300	400	500
2	2	True Value	50	50	50	50	50						
		Mean, no assignment error	49	48	44	47	49	Z-statistic	0.00	0.02	0.06	0.03	0.01
		SD	184	126	101	86	77	p-value	1.00	0.99	0.95	0.98	0.99
		Mean, stock assignment error	184	191	174	191	192	Z-statistic	0.37	0.55	0.63	0.79	0.87
		SD	363	257	198	179	164	p-value	0.71	0.58	0.53	0.43	0.39
		Mean, stock and age assignment error	201	201	185	196	204	Z-statistic	0.42	0.56	0.66	0.82	0.94
		SD	362	270	204	179	164	p-value	0.68	0.58	0.51	0.42	0.35
	3	True Value	300	300	300	300	300						
		Mean, no assignment error	295	295	303	284	309	Z-statistic	0.01	0.02	0.01	0.08	0.04
		SD	461	291	248	212	194	p-value	0.99	0.99	0.99	0.94	0.96
		Mean, stock assignment error	1,215	1,142	1,185	1,137	1,194	Z-statistic	1.04	1.42	1.73	2.01	2.21
		SD	878	591	510	416	404	p-value	0.30	0.15	0.08	***0.04***	***0.03***
		Mean, stock and age assignment error	1,213	1,139	1,183	1,133	1,191	Z-statistic	1.05	1.41	1.72	1.99	2.20
		SD	873	595	514	418	405	p-value	0.30	0.16	0.09	***0.05***	***0.03***
	4	True Value	200	200	200	200	200						
		Mean, no assignment error	212	173	203	203	206	Z-statistic	0.03	0.11	0.02	0.01	0.04
		SD	394	247	211	184	164	p-value	0.98	0.91	0.99	0.99	0.97
		Mean, stock assignment error	819	738	779	773	806	Z-statistic	0.85	1.06	1.47	1.67	1.93
		SD	724	510	395	344	314	p-value	0.39	0.29	0.14	0.10	***0.05***
		Mean, stock and age assignment error	761	720	752	757	778	Z-statistic	0.79	1.07	1.40	1.58	1.83
		SD	707	488	395	352	315	p-value	0.43	0.29	0.16	0.11	0.07
	5	True Value	50	50	50	50	50						
		Mean, no assignment error	52	51	51	48	47	Z-statistic	0.01	0.00	0.01	0.02	0.04
		SD	189	127	110	89	77	p-value	0.99	1.00	1.00	0.99	0.97
		Mean, stock assignment error	199	202	199	189	189	Z-statistic	0.38	0.55	0.71	0.79	0.84
		SD	392	276	210	176	164	p-value	0.70	0.58	0.48	0.43	0.40
		Mean, stock and age assignment error	240	213	217	204	207	Z-statistic	0.46	0.58	0.75	0.85	0.92
		SD	414	279	222	181	171	p-value	0.65	0.56	0.45	0.40	0.36
3	2	True Value	5,000	5,000	5,000	5,000	5,000						

Table H2. Mean and SD for 500 iterations estimating number by stock and age for three scenarios and results of test of null hypothesis that there is no difference between the mean of the estimate and the true value.

Stock	Age		Mean and Standard Deviation of Iterations					Ho: No bias in estimates, i.e., Mean-True Value = 0.0					
			Sample Size						Sample Size				
			100	200	300	400	500		100	200	300	400	500
		Mean, no assignment error	4,913	4,986	4,949	4,959	4,981	Z-statistic	0.05	0.01	0.05	0.05	0.02
		SD	1,717	1,264	997	900	833	p-value	0.96	0.99	0.96	0.96	0.98
		Mean, stock assignment error	4,738	4,798	4,757	4,782	4,787	Z-statistic	0.16	0.16	0.25	0.25	0.27
		SD	1,671	1,251	987	881	787	p-value	0.88	0.87	0.81	0.80	0.79
		Mean, stock and age assignment error	5,069	5,183	5,090	5,128	5,119	Z-statistic	0.04	0.14	0.09	0.14	0.15
		SD	1,740	1,308	1,023	928	806	p-value	0.97	0.89	0.93	0.89	0.88
	3	True Value	30,000	30,000	30,000	30,000	30,000						
		Mean, no assignment error	30,002	30,012	29,945	29,881	29,947	Z-statistic	0.00	0.01	0.03	0.07	0.04
		SD	3,112	2,377	1,910	1,645	1,398	p-value	1.00	1.00	0.98	0.94	0.97
		Mean, stock assignment error	28,805	28,834	28,801	28,728	28,758	Z-statistic	0.39	0.48	0.64	0.80	0.89
		SD	3,075	2,425	1,884	1,582	1,402	p-value	0.70	0.63	0.52	0.42	0.38
		Mean, stock and age assignment error	28,681	28,567	28,589	28,475	28,521	Z-statistic	0.43	0.61	0.73	0.96	1.02
		SD	3,072	2,357	1,931	1,584	1,445	p-value	0.67	0.54	0.47	0.34	0.31
	4	True Value	20,000	20,000	20,000	20,000	20,000						
		Mean, no assignment error	20,009	20,024	20,064	20,056	20,095	Z-statistic	0.00	0.01	0.04	0.04	0.07
		SD	2,988	2,201	1,739	1,449	1,299	p-value	1.00	0.99	0.97	0.97	0.94
		Mean, stock assignment error	19,167	19,247	19,256	19,260	19,286	Z-statistic	0.29	0.35	0.44	0.51	0.56
		SD	2,875	2,155	1,684	1,446	1,276	p-value	0.77	0.73	0.66	0.61	0.58
		Mean, stock and age assignment error	18,437	18,675	18,669	18,664	18,718	Z-statistic	0.54	0.63	0.80	0.92	1.00
		SD	2,890	2,111	1,673	1,447	1,277	p-value	0.59	0.53	0.43	0.36	0.32
	5	True Value	5,000	5,000	5,000	5,000	5,000						
		Mean, no assignment error	5,018	5,004	5,000	5,044	4,996	Z-statistic	0.01	0.00	0.00	0.05	0.01
		SD	1,694	1,197	1,010	878	804	p-value	0.99	1.00	1.00	0.96	1.00
		Mean, stock assignment error	4,789	4,804	4,808	4,850	4,807	Z-statistic	0.13	0.17	0.19	0.17	0.25
		SD	1,653	1,162	992	868	781	p-value	0.90	0.87	0.85	0.86	0.80
		Mean, stock and age assignment error	5,313	5,256	5,274	5,354	5,280	Z-statistic	0.17	0.22	0.26	0.37	0.34
		SD	1,800	1,185	1,037	948	821	p-value	0.86	0.83	0.79	0.71	0.73
4	2	True Value	500	500	500	500	500						
		Mean, no assignment error	507	530	491	526	491	Z-statistic	0.01	0.07	0.03	0.09	0.04

Table H2. Mean and SD for 500 iterations estimating number by stock and age for three scenarios and results of test of null hypothesis that there is no difference between the mean of the estimate and the true value.

Stock	Age		Mean and Standard Deviation of Iterations					Ho: No bias in estimates, i.e., Mean-True Value = 0.0					
			Sample Size						Sample Size				
			100	200	300	400	500		100	200	300	400	500
		SD	563	411	349	285	239	p-value	0.99	0.94	0.98	0.93	0.97
		Mean, stock assignment error	404	426	402	417	390	Z-statistic	0.18	0.20	0.32	0.32	0.50
		SD	519	378	303	258	218	p-value	0.85	0.85	0.75	0.75	0.61
		Mean, stock and age assignment error	439	454	423	445	429	Z-statistic	0.11	0.12	0.26	0.21	0.31
		SD	555	393	299	265	232	p-value	0.91	0.91	0.80	0.84	0.76
	3	True Value	3,000	3,000	3,000	3,000	3,000						
		Mean, no assignment error	3,000	2,982	3,065	3,011	2,992	Z-statistic	0.00	0.02	0.08	0.02	0.01
		SD	1,271	983	776	676	601	p-value	1.00	0.99	0.93	0.99	0.99
		Mean, stock assignment error	2,404	2,399	2,421	2,391	2,401	Z-statistic	0.52	0.65	0.84	1.04	1.08
		SD	1,150	918	691	586	554	p-value	0.60	0.51	0.40	0.30	0.28
		Mean, stock and age assignment error	2,370	2,367	2,412	2,381	2,370	Z-statistic	0.54	0.70	0.84	1.04	1.12
		SD	1,170	904	698	598	561	p-value	0.59	0.48	0.40	0.30	0.26
	4	True Value	2,000	2,000	2,000	2,000	2,000						
		Mean, no assignment error	2,036	2,005	1,977	2,018	1,987	Z-statistic	0.03	0.01	0.04	0.03	0.03
		SD	1,183	778	618	578	512	p-value	0.98	1.00	0.97	0.97	0.98
		Mean, stock assignment error	1,649	1,619	1,596	1,640	1,592	Z-statistic	0.33	0.52	0.72	0.72	0.92
		SD	1,062	728	564	501	445	p-value	0.74	0.60	0.47	0.47	0.36
		Mean, stock and age assignment error	1,613	1,581	1,546	1,571	1,538	Z-statistic	0.37	0.58	0.78	0.83	1.01
		SD	1,041	723	584	516	457	p-value	0.71	0.56	0.44	0.41	0.31
	5	True Value	500	500	500	500	500						
		Mean, no assignment error	505	497	501	526	501	Z-statistic	0.01	0.01	0.00	0.09	0.00
		SD	541	404	322	296	255	p-value	0.99	0.99	1.00	0.93	1.00
		Mean, stock assignment error	411	405	391	423	397	Z-statistic	0.19	0.26	0.38	0.29	0.45
		SD	466	359	289	260	226	p-value	0.85	0.79	0.71	0.77	0.65
		Mean, stock and age assignment error	445	447	429	475	443	Z-statistic	0.11	0.14	0.24	0.09	0.24
		SD	501	380	300	272	237	p-value	0.91	0.89	0.81	0.93	0.81

APPENDIX I. Curriculum Vitae of Expert Panel Members.

RESUME

John H. Clark, Ph.D.
Juneau, Alaska

EDUCATION

1963 to 1965 Valdez High School, Valdez, Alaska

1965 to 1967 Helena High School, Helena, Montana (Graduated, 5/67)

1968 to 1971 Carroll College, Helena Montana,
B. A. in Biology, graduated with CUM Laude honors, authored an honors thesis titled "Kokanee Salmon (*Oncorhynchus nerka*) in Helena Valley Reservoir".

1971 to 1974 Colorado State University, Fort Collins, Colorado,
M. S. in Fisheries Biology, authored a thesis titled "*Variability of Northern Pike Pond Culture Production*".

1973 to 1975 Colorado State University, Fort Collins, Colorado,
Ph.D. in Fisheries Biology, authored a thesis titled "*Management Evaluation of Stocked Northern Pike in Colorado's Small Plains Reservoirs*". Minor in genetics/evolution.

HONORARIES

Sigma Xi	Associate Member
Phi Kappa Phi	Full Member
Outstanding Young Men of America	Awarded in 1979

CERTIFICATES

Certified Fisheries Scientist AFS - No. 1361 - March 1980

SCIENTIFIC AND PROFESSIONAL AWARDS

Meritorious Service Award - 1989 – Alaska Chapter of American Fisheries Society
Public Service Commendation Award – 1989 – State of Alaska
Sefvie Award – 1992- Habitat and Restoration Division, AK Dept. of Fish and Game
Conservation and Management Service Award – 1995 - AK Dept. of Fish and Game
Wallace H. Norenberg Award – 1997 - Alaska Chapter of American Fisheries Society
Governors Recognition Award – 1999 – Negotiation of the Pacific Salmon Treaty

EMPLOYMENT

1969	U.S. Forest Service, Helena National Forest, Helena, Montana. Summer employee.
1970 - 1971	Montana Department of Fish and Game, Helena, Montana. Fishery Technician.
1971 - 1975	Colorado Cooperative Fishery Unit, Colorado State University, Fort Collins, Colorado. Graduate Research Assistant.
1975 - 1979	Alaska Department of Fish and Game, Anchorage, Alaska. Research Project Leader (FB III), Commercial Fisheries Division.
1979 - 1984	Alaska Department of Fish and Game, Juneau, Alaska, Chief Fisheries Scientist, Commercial Fisheries Division.
1984 - Mar 1989	Alaska Department of Fish and Game, Fairbanks, Alaska. Regional Supervisor, Sport Fish Division.
Apr 1989 - Sep 1989	Alaska Department of Fish and Game, Juneau, Alaska. Acting Director of Oil Spill Impact Assessment and Restoration Division.
Sep 1989 - Jun 1993	Alaska Department of Fish and Game, Fairbanks, Alaska. Regional Supervisor, Sport Fish Division.
Jul 1993 – Oct 1995	Alaska Department of Fish and Game, Juneau, Alaska. Fishery Biologist IV, Commercial Fisheries Management and Development Division.
Dec 1995 – Nov 2003	Alaska Department of Fish and Game, Helena, Montana Fishery Scientist I, Commissioners Office.
Dec 2003 – Present	Alaska Department of Fish and Game, Juneau, Alaska, Chief Fisheries Scientist, Commercial Fisheries Division.

TEACHING APPOINTMENTS

1973 - 1975	Graduate Teaching Assistant, Colorado State University, Fort Collins, Colorado.
1975	Assistant Professor, Colorado State Univ., Fort Collins, Colorado.
1976 to 1990	Affiliate Faculty Appointment, Southeastern Senior College, Juneau, Alaska.
1977 to 1995	Affiliate Faculty Appointment, University of Alaska at Fairbanks, Fairbanks, Alaska.
1979 to 1990	Affiliate Faculty Appointment, University of Washington, Seattle, Washington.

AGENCY AND INTERAGENCY COMMITTEE MEMBERSHIP

Scientific and Statistical Committee of the North Pacific Fisheries Management Council
Member from 1980-1985

Biological Review Team for National Marine Fisheries Service for application of the Endangered Species Act to anadromous salmon in the Pacific Northwest
Represented State of Alaska from 1992 to 1994

Chinook Technical Committee of the Pacific Salmon Commission
Member from 1994 to present.

Coho Technical Committee of the Pacific Salmon Commission
Member from 1994 to present.

Transboundary Technical Committee of the Pacific Salmon Commission
Non member, but active participant at times since 1994.

Escapement Goal Policy Implementation Team of the AK Department of Fish and Game
Member from 2001 to present.

Science Panel for the Southeast Sustainable Fishery Fund
Member since 2002

PUBLICATIONS

Authored, co-authored or ghost written between 150 and 200 technical fishery reports over the past 30 years. Some of this technical matter is included in various chapters of printed books and some is in scientific journals, but most is printed in the gray literature used for stock assessment and management of Alaskan fisheries. Subject matter has ranged from stock assessment techniques for California gray whales along the Baja Peninsula in Mexico to stock assessment of inter-tidal seaweed along the shores of the Alaskan coast near Togiak to the unique approach the State of Alaska takes in management of Pacific salmon. Most of my published work involves stock assessment of salmon and freshwater fish.

Summary Professional Vitae

Richard B. Deriso

Inter-American Tropical Tuna Commission
Scripps Institution of Oceanography
La Jolla, CA 92093-0203

Formal Education

University of Washington
Ph.D. in Biomathematics (Quantitative Ecology) 1978

University of Florida
M.S. in Mathematics 1975

Auburn University
B.S. in Industrial Engineering 1972

Academic Honors

Tau Beta Pi, Pi Alpha Mu (scholastic honor societies)
1981 W. F. Thompson Award from American Institute of Fishery Research Biologists for publication (Deriso, 1980 CJAFS).

Major Research Interests

Fisheries Population Dynamics, Quantitative Ecology, applied mathematics, statistics.

Recent Professional Experience

Chief Scientist of the Tuna-Billfish Program, Inter-American Tropical Tuna Commission, 1988 - present.

Associate Adjunct Professor, Scripps Institution of Oceanography, UCSD, 1990 - present.

Ocean Studies Board member, U.S. National Research Council. 2002- present.

Affiliate Associate Professor of Fisheries, University of Washington, 1987 - present; 1982-1986, Assistant Professor.

Scientific and Statistical Committee member, Western Pacific Regional Fisheries Management Council, 1993 - present.

Population Dynamicist, International Pacific Halibut Commission, Seattle, WA, 1980 - 1988.

Visiting Research Assistant Professor, Marine Sciences, University of North Carolina at Chapel Hill, 1979 - 1980.

Consultant to several agencies and institutions, including US Minerals Management Service, Exxon, Essa Technologies Ltd., Australian Fisheries Management Agency, Great Lakes Fishery Commission, Ontario Ministry of Natural Resources, University of Alaska at Juneau, Applied Biomathematics Inc., Living Marine Resources Inc., National Marine Fisheries Service, North Carolina Sea Grant Program, US Environmental Protection Agency, New York State Department of Environmental Conservation, and Public Service Electric and Gas Company of New Jersey.

Other Professional Activities

Over 30 seminars given at various universities, agencies, and conferences.

Taught several graduate courses, including
FISH 557 course (Theoretical Models of Exploited Animal Populations, University of Washington) , QSCI 598 (Decision analysis for exploited populations, University of Washington), SIO 276 (Quantitative theory of populations and communities, Scripps Institution of Oceanography, with G. Sugihara).

Served on several committees and working groups, including groups with ICES, FAO, NAS, and NRC. Past co-chairman, NRC Committee on Fish Stock Assessment Methods.

Publications And Reports

Over 50 publications and reports, including

Deriso, R.B. 1978. Non-linear age-structured models for seasonally breeding populations. Ph.D. dissertation, University of Washington. 159 p.

Deriso, R.B. 1980. Harvesting strategies and parameter estimation for an age-structured model. Can. J. Aquat. Sci. 37: 268-282.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch--age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:815-824.

Deriso, R.B., R.G.Punsly, and W.H. Bayliff. 1991. A Markov movement model of yellowfin tuna in the Eastern Pacific Ocean and some analyses for international management. Fish. Res. 11: 375-395.

Quinn, T.J.II and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, NY,NY. 542p.

Deriso, R. B., D. R. Marmorek, and I. J. Parnell. 2001. Retrospective patterns of differential mortality and common year-effects experienced by spring and summer chinook salmon (*Oncorhynchus tshawytacha*) of the Columbia River. Can. J. Fish. Aquat. Sci., 58 (12): 2419-2430.

John Carlos Garza
Santa Cruz Laboratory
NOAA Southwest Fisheries Science Center
110 Shaffer Road
Santa Cruz, CA 95060 U.S.A.
(831) 420-3903
carlos.garza@noaa.gov, carlosjg@ucsc.edu

Professional Positions

Supervisory Research Geneticist and Team Leader 1999-present
Molecular Ecology and Genetics Team
Southwest Fisheries Science Center, Santa Cruz Laboratory

Assistant Adjunct Professor of Ocean Sciences 2001-present
University of California, Santa Cruz

Education:

Doctor of Philosophy in Integrative Biology 1998
University of California, Berkeley (UCB)

Master of Science in Biology 1991
University of California, San Diego

Bachelor of Arts in Biology 1990
University of California, San Diego (UCSD)

Selected Publications

Pastor T, **Garza JC**, Allen P, Amos W, Aguilar A (2004). Low genetic variability in the highly endangered Mediterranean monk seal. Journal of Heredity: in press.

Wlasiuk G, **Garza JC**, Lessa EP (2003) Genetic and geographic differentiation in the Río Negro tuco-tuco (*Ctenomys rionegrensis*): inferring the roles of migration and drift from multiple genetic markers. Evolution 57: 913-926.

Garza JC, Williamson E (2001) Detection of reduction in population size using data from microsatellite DNA. Molecular Ecology 10: 305-318

Garza JC, Dallas J, Duryadi D, Gerasimov S, Croset H, Boursot P (1997) Social structure of the Mound-building mouse, *Mus spicilegus*, revealed by genetic analysis with microsatellites. Molecular Ecology 6: 1009-1017.

Garza JC, Freimer NB (1996) Homoplasy for size at microsatellite loci in humans and chimpanzees. Genome Research 6: 211-217.

Garza JC, Slatkin M, Freimer NB (1995) Microsatellite allele frequencies in humans and chimps with implications for constraints on allele size. Molecular Biology and Evolution 12: 594-603.

Di Rienzo A, Peterson AC, **Garza JC**, Valdes AM, Slatkin M, Freimer NB (1994) Mutational processes of simple-sequence repeat loci in human populations. Proceedings of the National Academy of Sciences, USA 91: 3166-3170.

Garza JC, Woodruff DS (1992) A phylogenetic study of the gibbons (*Hylobates*) using DNA obtained non-invasively from hair. Molecular Phylogenetics and Evolution 1: 202-210.

Oral Presentations:

I have given numerous invited public presentations. These include departmental and other invited seminars at UCs San Diego, Berkeley and Santa Cruz, UN Reno, San Francisco State, Stanford, Moss Landing Marine Lab, Santa Clara University, Oxford University, University of Barcelona, University of Montpellier and the Zoological Institute of London.

Honors and Awards:

National Science Foundation Postdoctoral Fellowship	1998
University of California President's Postdoctoral Fellowship	1998
UCB Chancellor's Dissertation Year Fellowship	1997
Ford Foundation Dissertation Year Fellowship	1997
UCSD Chancellor's Volunteer Award	1991
UCSD graduation: Magna Cum Laude	1990
Phi Beta Kappa Honor Society	1989

Professional Service:

Member: Editorial Board, Molecular Ecology

Editorial Reviewer: American Journal of Human Genetics, Animal Conservation, Canadian Journal of Zoology, Conservation Genetics, Genetics, Heredity, Journal of Molecular Evolution, Journal of Sea Research, Molecular Biology and Evolution, Molecular Ecology, Nature Genetics, Nucleic Acids Research, Proceedings of the National Academy of Sciences, Transactions of the American Fisheries Society and Zoo Biology.

Application Reviewer: National Science Foundation, Saltonstall/Kennedy Grant Program, UC Office of the President Postdoctoral Fellowship.

Meeting Co-Organizer: 2000 annual meeting of the California Population and Evolutionary Geneticists, UC Santa Cruz.

Member: Federal Technical Recovery Team for ESA listed Salmonids in the North Central California Coast Planning Domain;

Member: Russian River Coho Salmon Recovery Planning Workgroup.

BRIEF CURRICULUM VITAE

David Gregory Hankin
756 9th Avenue
Trinidad, CA 95570
(707) 677-0633

January 2004

Education:

B.A., Biology, Reed College, Portland, Oregon. 1971. Ph.D., Fishery Science (Minors in Biometrics, Public Policy), Cornell University, Ithaca, New York. 1978.

Appointments & Positions:

2001-present: Chairman, Department of Fisheries Biology, Humboldt State University. 1976-present: Assistant/Associate/Full Professor, Department of Fisheries, Humboldt State University, Arcata, California. 2001-present: appointed US member of Committee on Scientific Cooperation, Pacific Salmon Commission; 1994-1998: Chairman (rotating), Department of Fisheries, Humboldt State University. 1994: Visiting Scientist, National Institute of Water and Atmospheric Research, Christchurch, New Zealand (sabbatic leave); member, California Sea Grant Committee (1989-present); At-Large Appointed Member, Scientific and Statistical Committee, Pacific Fishery Management Council (1987-1992; Vice-Chair 1988-1990); 1985-1987 Visiting Associate Professor, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon (25%: 85-86); Co-leader, Oregon Department of Fisheries and Wildlife's Chinook Salmon Planning Team (75%: 85-86; 100%: 86-87). 1984-1985: Visiting Sea Grant Professor, Department of Fisheries and Wildife, Oregon State University, Corvallis, Oregon. (non-teaching sabbatic leave for academic year); 1980-1983: Director of Graduate Studies, College of Natural Resources, Humboldt State University (half-time release for a three year term).

Partial List of Publications (Salmon & Stream Sampling only)

Hankin, D.G., and J. Fitzgibbons. 2003. Long-term effects of mating practices and size-selective ocean fisheries on age and sex composition of chinook salmon populations returning to hatcheries. (in prep; based on Contract report submitted to Yurok Tribe, Klamath, CA)

Hankin, D.G. , and D. McCanne. 2000. Estimating the number of fish killed in the Cantara Spill and the proportions of wild and hatchery trout. Calif. Fish Game.

Welsh, H.H., L.M. Ollivier, and D.G. Hankin. 1997. A habitat-based design for sampling and monitoring stream amphibians with an illustration from Redwood National Park. Northwestern Naturalist 78: 1-16.

Hankin, D.G., J.W. Nicholas, and T.W. Downey. 1993. Evidence for inheritance of age of maturity in chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Fish. Aquat. Sci. 50: 347-358

Dolloff, C.A., D.G. Hankin, and G.H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service, General Technical Report SE-83. 25 pp

Nicholas, J., and D. G. Hankin. 1988. Chinook salmon populations in Oregon's coastal river basins: Description of life histories and assessment of recent trends in run strength. Oregon Dept. of Fish and Wildlife, Information Report 88-1. 359 pp.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45: 834-844.

Hankin, D. G., and M. C. Healey. 1986. Dependence of exploitation rates for maximum yield and stock collapse on age and sex structure of chinook salmon stocks. Can. J. Fish. Aquat. Sci. 43: 1746-1759.

Hankin, D. G. 1986. Sampling designs for estimation of the total number of fish in small streams. Research Paper PNW-360, Pacific Northwest Research Station, U.S. Forest Service, Portland, OR. 33 pp.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. 41: 1575-1591.

Hankin, D. G. 1982. Estimating escapement of Pacific salmon: marking practices to discriminate wild and hatchery fish. Trans. Am. Fish. Soc. 111: 286-298.

Sketch of Research Activities

1. For the past 20 years Hankin has taught a senior/graduate level sampling theory course at HSU and he has been a leader in development of survey designs for estimation of abundance of fish (especially juveniles salmon and trout) in small streams. His stream survey design methods (Hankin 1984, Hankin and Reeves 1988) have been adopted throughout the Pacific Northwest and to a lesser extent in clearwater streams in the Southeastern US.

2. For the past 25 years, Hankin has been actively involved in study of life history variation, population and fishery dynamics of Pacific salmon, with emphasis on chinook salmon. His models of the impact of exploitation on chinook salmon (Hankin and Healey 1986) have formed the basis for harvest rate management of Klamath River chinook salmon off northern California and southern Oregon and for sharing of allowable catches between commercial, recreational and tribal fishers.

3. For the past 25 years, Hankin has been concerned about the status of wild populations of salmon and the possible impact that hatchery production may have on wild stocks. These concerns have caused him to focus on development of hatchery marking programs that allow estimation of the proportion of hatchery fish among returning adults (Hankin 1982) and on development of mating practices that may prevent unintentional selection for earlier age at maturity in hatchery populations of chinook salmon.

Gary S. Morishima
P.O. Box 1563, Mercer Island, WA 98040
Summary Vitae

Education:

- Ph.D. Quantitative Science & Environmental Management, University of Washington (major subjects include fisheries population dynamics, operations research, resource economics, numerical analysis, mathematical statistics)
- B.S., Mathematics, University of Washington

Professional Experience:

- Over thirty years experience in computer simulation modeling, natural resource management (forestry, fisheries, economics), legislative processes, policy analysis, mathematical statistics, workshop organization and conduct, conflict resolution, and meeting facilitation.
- CEO, MORI-ko L.L.C., Natural Resource Consulting Firm, since 1969. Consultant and expert witness in legislative and judicial processes in areas pertaining to computer simulation of natural resource management systems, statistical analysis, forestry, and fisheries management.
- Technical Advisor, Natural Resources, Quinault Nation, since 1979.
- Forest Manager, Quinault Nation, 1974-1979.
- Ford Fellow, Center for Quantitative Science in Fisheries, Forestry, and Wildlife, University of Washington
- Systems Analyst, Boeing Company

Current activities:

- Executive Board, Intertribal Timber Council (since 1977)
- Salmon Technical Team, Pacific Fishery Management Council (since 1981, including past chair)
- Pacific Salmon Commission Technical Committees (since 1985):
  - Coho (U.S. Section Chair)
  - Joint Interceptions (U.S. Section Chair)
  - Selective Fishery Evaluation (U.S. Section Chair)
  - Chinook
  - Data Sharing

Past Activities:

- Member, National Task Force on Tribal-Federal Relations, U.S. Forest Service (1999-2003)
- Technical Advisor, Tribal Leaders Task Force on Trust Reform
- Intergovernmental Advisory Committee (appointed by the U.S. Secretary of Agriculture) to provide advice in implementing the Northwest Forest Plan (1993-2000, currently serving as an alternate)

- Member, Drafting Team on Secretarial Order on *American Indian Tribal Rights, Federal-Tribal Trust Responsibilities, and the Endangered Species Act* (signed by the Secretaries of Interior and Commerce in 1999).
- Salmon & Steelhead Advisory Commission (appointed by the U.S. Secretary of Commerce), from 1982-1985.
- Various Task Forces on Indian Self-Determination and Education Assistance Act, Self-Governance, Fiscal Management systems of the Bureau of Indian Affairs, American Indian Policy Review Commission.
- Chair, Task Force for developing regulations to implement the National Indian Forest Resources Management Act.
- Policy Advisory Team for Natural Resources for former Washington State Governor Booth Gardner

Awards:

- *National Earle Wilcox* Award for Outstanding Contributions to Indian Forestry, Intertribal Timber Council
- *Pride in Excellence* Award, Boeing Company

RESUME

Brian E Riddell, PhD, BSc

Research Scientist, DFO, Pacific Biological Station, Nanaimo, BC

Home: 517 Greenbriar Place, Nanaimo, BC V9T 4E8

(250-758-4058)

1979 Ph.D., McGill University, Dept. Biology (Population biology/genetics)
Environmental and Genetic sources of geographic variation in populations of Atlantic salmon (Salmo salar L.) supervisor: Dr. W. Leggett.
1974 B.Sc., Guelph Univeristy, Dept. Biology (Marine Biology)

Employment History:

Sept. 1979. **Research Scientist, Pacific Biological Stations, SE-RES-01**
1981. **Promotion to SE-RES-02**
1982. **Head, Salmon Populations Section, initiated the Salmon Genetics Program. Designed,with Mr. Bob Humphries, and managed the Rosewall Creek Quantitative Genetics facility.**
1985. **Head, Salmon Stock Assessment program, initiated regional program for science-based stock assessment, first Chair-person, Pacific Stock Assessment Review Committee, Salmon Sub-committee. Chair of Salmon Sub-Committee until 1992, and member of PSARC Steering Committee until senior process changed in late 1990s.**
1987. Head, Salmon Production Section, combined programs in stock assessment, salmon biology, and enhancement assessment including lake enrichment program. (110 staff in all aspects of the biology and assessment of Pacific salmon in BC and the Yukon)
1990. Promotion to SE-RES-03
1991. Promotion to SE-RES-04
1994. Program Head, Stock Assessment and Forecasting (new organization structure implemented in Nov. '94), managed Fraser River programs for Stock Assessment.
1995. Program Head, Chinook and Coho Stock Assessment program, requested to develop a program focused on the assessment and management of Chinook and Coho salmon in BC. (same supervisory position until secondment to PFRCC)
Sept. 2001 – April 2004. Science Advisor, Pacific Fisheries Resource Conservation Council, Vancouver, B.C. (Hon. J. Fraser, Chair)
April 2004 – Advisor on Pacific Salmonids, Office of the Director, Science Branch, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC.
April 2005 – Director, Pacific Salmon and Freshwater Ecosystems Division, Science Branch, Pacific Biological Station, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC.

Related Appointments:

1980-1984 technical committees, International North Pacific Fisheries Commission.
1985 – 2002 member of the Salmon Sub-Committee, Pacific Science Advice Review Committee (Chair of Sub-committee for 5 years).

1983-2002 Canadian Chair, Chinook Technical Committee of the Pacific Salmon Commission. **1985-1999**, Canadian member, Standing Committee for Statistics and Research, Pacific Salmon Commission. Senior technical advisory on many issues concern Pacific Salmon Treaty.
1987-1989 Associate Editor for Genetics, American Fisheries Society
1989-1991 Chair, International Symposium on the Interaction of Enhanced and Wild Salmonids (June 17-20, 1991), Nanaimo, BC.
1992-1995 U.S. National Research Council, Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (publication Upstream: Salmon and Society in the Pacific Northwest)
1996 to present. Member, Independent Scientific Advisory Board and Independent Scientific Review Panel (scientific advisory boards to NOAA Fisheries and Northwest Power Planning and Conservation Council for Fish and Wildlife Programs in the Columbia River Basin) in Pacific northwest United States.

Awards:
1989. Public Service of Canada Award of Merit for establishment of the chinook conservation program in the Strait of Georgia.
1994. Canada 125 Year Medal for citizenship in the community and contributions to the conservation of Pacific salmon.
1996. Public Service of Canada Award of Merit for responding to the 1995 Alaskan chinook fisheries and representing Canada in the U.S. supreme court case.
2000. Assistant Deputy Minister's Commendation Award for contributions to achieving the 1999 chinook agreement in the Pacific Salmon Treaty.
2000. Deputy Minister's Prix d'Excellence Award for contributions to the Department and the Public Service of Canada.

Fields of Research and Interest:

1. Population biology and genetics (quantitative and population) of Pacific salmonids, including conservation genetics of small populations and the impacts of intensive culture on enhanced and wild populations.
2. Population dynamics, life history, and fishing mortality estimates for Pacific salmon, in particular chinook salmon; and appropriate management regimes for Pacific salmonids.
3. Formulation of public policy for conservation and utilization of Pacific salmonids.

Society Memberships:
American Fisheries Society, member of Canadian Concerns section and Genetics section.
The American Society for the Study of Evolution, member
International Society for Conservation Biology, member

Recent Publications or Presentations:
Contributed approximately 40 primary publications and over 80 papers in technical or stock assessment and advisory reports for the Department, the Pacific Stock Assessment Review Committee, and the Pacific Salmon Commission. I have also contributed to 22

publications by the Independent Advisory Committees since 1996; 1 book, all committee publications are by consensus and multiple authorships. Examples are:

Riddell, B.E. 1993. Spatial Organization of Pacific salmon: what to conserve? Pp. 23-41. In *Genetic Conservation of Salmonid Fishes*, Ed. J.G. Cloud and G.H. Thorgaard. Plenum Press.

Bower, S.M., R.E. Withler, and B.E. Riddell. 1995. Genetic Variation in Resistance to the Hemoflagellate *Cryptobia salmositica* in Coho and Sockeye Salmon. *Journal of Aquatic Animal Health* 7(3): 185–194.

Committee on Protection and Management of Pacific Northwest Anadromous Salmonids. 1996. *Upstream: Salmon and Society in the Pacific Northwest*. National Academy Press. Washington, D.C. 1996. 452 p. (Committee chair: Dr. John Magnuson)

Chebanov, N.A. and B.E. Riddell. 1998. The spawning behaviour, selection of mates, and reproductive success of chinook salmon spawners of natural and hatchery origins under conditions of joint spawning. Journal of Icthyology 38: 517-526

Cass, A. and B. Riddell. 1999. A life history model for assessing alternative management policies for depressed chinook salmon from the west coast of Vancouver, B.C. ICES J. Marine Sci. 56: 414 -421.

ISAB. 2000. The Columbia River Estuary and the Columbia Basin Fish and Wildlife Program. Northwest Power Planning Council. ISAB 2001-05. 40pg.

ISAB. 2002. Hatchery surpluses in the Pacific northwest. Fisheries 27 (12): 16-27.

Riddell, B.E. 2002. Salmon Genetics: managing speculation and salmon. Keynote address at Second International Symposium on Stock Enhancement and Sea Ranching. Kobe, Japan. Feb. 2002.

Riddell, B.E., G. Brown and D. Chen. 2001. Spawning escapement goal for Harrison River white fall chinook, lower Fraser River. PSARC Working Paper S2001-16.

Riddell, B.E. et al. 2002. Review of 2001 chinook returns to the west coast of Vancouver Island, forecast of the 2002 return to Stamp River/Robertson Creek Hatchery indicator stock, and outlook for other WCVI chinook stocks. Can. Science Ad. Secr. Res.Docu. 2002/119. 43p.

Anon. 2001. Exploitation Rate Analysis and Model Calibration, Joint Chinook Technical Committee. TCCHINOOK (01)-2. 42p. + 10 appendices. Pacific Salmon Commission (www.psc.org)

Anon. 2002. Investigation of methods to estimate mortalities of unmarked salmon in mark-selective fisheries through the use of double index tag groups. Selective Fisheries Evaluation Committee, TCSFEC(02)-1. 87p. Pacific Salmon Commission (www.psc.org)

D.E. Gaudet, G. Morishima, B. Riddell. 2003. Technical background to the Chinook Annex of the 1999 Pacific Salmon Treaty Agreement. Special report of the Pacific Salmon Commission (to be posted to www.psc.org in Sept. 2003)

During 2002-04, the PFRCC has produced six technical reports covering their Annual Report 2001-2002 (Stock Assessment of Pacific salmon in Southern BC), the Broughton Archipelago Pink Salmon advisory, and the Aquaculture Advisory, Stock Assessment for Central and Northern BC, a technical review of over-escapement, and an Advisory on a proposed Aquaculture Forum for BC. (see www.fish.bc.ca)

DFO. 2003. Review of the 2002 Fraser River Sockeye Fishery. Department of Fisheries and Oceans, Vancouver, B.C. (member of External Steering Committee).

August 2003, Keynote speaker at the Annual Meeting of the American Fisheries Society. Title: Ecological Genetics of Fish Populations: an overview of fish, fisheries, and aquaculture. Conference symposium #37 Human Impacts on the Genetics and Ecology of Fishes.

Riddell, B.E. and R.J. Beamish. 2003. Distribution and Monitoring of Pink Salmon (*Oncorhynchus gorbuscha*) in British Columbia, Canada. (NPAFC Doc. 707). 33p. Science Branch, Pacific Region, Department of Fisheries and Oceans, Canada.

Bottom, D.L, B. Riddell, and J.A. Lichatowich. In press. Chapter 10. The Estuary, plume, and marine environments. *In* Return to the River. Elsevier (Academic Press). *Fall, 2005 release.*

Personal References:

Dr. Richard Beamish, Senior Scientist, Science Branch, Pacific Region (250-756-7029)

Dr. Carl Walters, Professor, University of British Columbia, BC (604-822-6320)

Honorable John Fraser, Chair, Pacific Fisheries Resource Conservation Council, Vancouver, B.C. (604-775-5583)

Carl Schwarz

Professor
Dept. of Statistics and Actuarial Science
Simon Fraser University
Burnaby, BC

Educational Background

1988 Ph.D. Statistics, University of Manitoba, Canada
Post-release stratification and migration models in band-recovery and capture-recapture models
1981 M. Math Statistics, University of Waterloo, Canada
1980 M.Sc. Computer Science Simulation and modeling, University of Manitoba, Canada
1978 B.Sc. Computer Science, University of Manitoba, Canada

Employment History at Academic Institutions

September 2001 - Current Professor, Statistics and Actuarial Science, Simon Fraser University
January 1994 - August 2001 Associate Professor, Department of Statistics and Mathematics, Simon Fraser University
July 1988 - December 1993 Assistant Professor, Department of Statistics, University of Manitoba
September 1987 - July 1988 Lecturer, Department of Statistics, University of Manitoba
September 1984 - July 1988 Consultant, Statistical Advisory Service, University of Manitoba
September 1984 - August 1987 Sessional Lecturer, Department of Statistics, University of Manitoba
Current Research Interests
My research program is in three areas: capture-recapture modeling of animal population dynamics; statistical consulting; and linear and generalized linear models. The research in capture-recapture models requires the development of new stochastic models, the development of model fitting and testing procedures, and the development of computer software. In large part, it is motivated by real problems encountered by ecologists. My interest in statistical consulting involves assistance in experimental design and analysis in complex experimental situations where the "standard textbook" results are not appropriate. Both of these areas give rise to my interest in linear and generalized linear models. My current research projects are:

- the development of capture-recapture methodology to estimate population parameters of temporally stratified populations. This has applications in estimating salmon escapement; in estimating salmon smolt runs; and in estimating sable fish populations.

- the development of capture-recapture methodology to estimate population parameters of long-lived animal populations that have temporary absences from the sampling areas. This will be applied to estimate the population size and survival rates of the seal herd on Sable Island, Nova Scotia. This population consists of long-lived animals with year-to-year temporary absences from the breeding colony, and within-year temporary absences from the beaches during multiple within-year surveys.
- the development of tag-recovery methodology to study migration among geographically-stratified populations. This has been used to study the movement of herring among spawning areas in B.C. and the movement of mallards among wintering areas in the southern United States. A new study is underway to examine the movement of hatchery released salmon from the coded-wire returns obtained from the fishery.
- the provision of statistical advice (through the Statistical Advisory Service) to graduate students and faculty at the University and to researchers off campus. For example, we are currently involved in a project to investigate the relationship between forest inventory data stored in a GIS and habitat data obtained by ground crews.

Refereed Publications (last five years)

Bonner, S. J. and Schwarz, C. J. (2004). Continuous time-dependent individual covariates and the Cormack-Jolly-Seber Model. Animal Biodiversity and Conservation, 27, 149-155.

Schwarz, C. J. and Bairlein, F. (2004). Dispersal and migration. Animal Biodiversity and Conservation 27, 297-298.

Sutherland, J. and Schwarz, C. J. (2004). Multi-List Methods Using Incomplete Lists in Closed Populations. Biometrics 61. 134-140.

Demson, J. B., O'Connell, M. F., and Schwarz, C. J. (2004). Spatial and temporal variation in abundance of Atlantic salmon, Salmo salar, with emphasis on impacts of the closure of the Newfoundland commercial fishery. Fisheries Management and Ecology 11, 387–402.

Dempson, J. B., Schwarz, C. J., Shears, M., and Furey, G. (2004). Comparative proximate body composition of Atlantic salmon with emphasis on parr from fluvial and lacustrine habitats. Journal of Fish Biology 64, 1257–1271.

McPherson, R. J., Arnold, T. W., Armstrong, L. M., and Schwarz, C. J. (2003). Estimation of the nest survival rate and the number of nests initiated per breeding pair. Journal of Wildlife Management 67, 843-851. McPherson was a summer NSERC student.

Manske. M., Stobo, W.T. and Schwarz, C.J. (2002). Estimation of age-specific probabilities of first return to the breeding colongy and annual survival rates for the male Grey Seal (Halichoerus ryprus) on Sable Island from capture-recapture data. Marine Mammal Science 18, 145-155.

Pledger, S. and Schwarz, C.J. (2002). Modelling heterogeneity as a random effect using mixture models. Journal of Applied Statistics, 39, 315-328. In: Morgan, B.J.T.

and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Seber, G. A. F. and Schwarz, C. J. (2002). Capture-recapture: before and after EURING 2000. Journal of Applied Statistics, 29, 459-474. In: Morgan, B.J.T. and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Schwarz, C. J. (2002). Real and quasi-experiments in capture-recapture. Journal of Applied Statistics, 29, 459-474. In: Morgan, B.J.T. and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Arnason, A. N. and Schwarz, C. J. (2002). POPAN-6: Exploring convergence and estimate properties with SIMULATE. Journal of Applied Statistics 29, 649-688. In: Morgan, B.J.T. and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Schwarz, CJ (2002). Discussion comments on `Prior distributions for stratified capture-recapture models' Journal of Applied Statistics 29, 239-240. In: Morgan, B.J.T. and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Barker, R., Cooch, E., Schwarz, C (2002). Discussion comments on: `Approaches for the direct estimation of Lambda and demographic contributions to Lambda, using capture-recapture data' Journal of Applied Statistics, 29, 569-572. In: Morgan, B.J.T. and Thomson, D.L. (Eds.)(2002) 'Statistical Analysis of Data from Marked Bird Populations' Journal of Applied Statistics 29, nos 1-4.

Schwarz, C. J. (2001). The Jolly-Seber model: more than just abundance. Journal of Agricultural, Biological, and Environmental Statistics 6, 195-205.

Dempson, J. B., Schwarz, C. J., Reddin, D. G., O'Connell, M. F., Mullins, C. C., and Bourgeois, C. E. (2001). Estimation of marine exploitation rates on Atlantic salmon (Salmo salar L.) stocks in Newfoundland, Canada. ICES Journal of Marine Science 58, 331-341.

Dauk, P.C. and Schwarz, C. J. (2001). Catch estimation with restricted randomization in the effort survey. Biometrics 57, 461-468.

Dauk, P. C. and Schwarz, C. J. (2001). Catch estimation in the presence of declining catch rate due to gear saturation. Biometrics 57, 287-293.

Schwarz, C. J. and Arnason, A. N. (2000). The estimation of age-specific breeding probabilities from capture-recapture data. Biometrics 56, 59-64.

Schwarz, C. J. and Stobo, W. T. (2000). The estimation of age-specific pupping probabilities for the grey seal (Halichoerus grypus) on Sable Island from capture-recapture data. Canadian Journal of Fisheries and Aquatic Sciences 57, 247-253.

Manske, M. and Schwarz, C. J. (2000). Estimates of stream residence time and escapement based on capture-recapture data. Canadian Journal of Fisheries and Aquatic Sciences 57, 241-246.

James B. Scott, Jr.
Chief Fish Scientist
Washington Department of Fish and Wildlife
600 Capitol Way N, Olympia, WA 98501
Ph: 360-902-2736; e-mail: scottjbs@dfw.wa.gov

Education

M.S., Fisheries, University of Washington 1982
B.S., Fisheries, University of Washington 1980

Professional Experience

Mr. Scott joined the Washington Department of Fish and Wildlife (WDFW) in 1999 to lead the newly created Fish Science Division. His primary area of expertise is biometrics, including computer simulation and analytical models of biological systems. This expertise has been applied in a variety of applications in domestic and international forums. He served as co-chair of the Pacific Salmon Commission Chinook Technical Committee from 1991 through 2001, and was a technical advisor for the renegotiation off the Pacific Salmon Treaty in 1999. Since joining WDFW, his work has focused on developing procedures to evaluate the risks and benefits of artificial production and developing recovery plans for listed species of salmonids. As manager of the Science Division, comprised of over 130 FTEs, he has the responsibility of assuring that the production and management of fish resources by WDFW is grounded on a sound scientific basis.

Positions

1999-Present, Chief Fish Scientist, WDFW
Responsible for development of agency plan for research and data collection and for management of the Fish Science Division (more than 130 FTEs).
Serve as agency expert on fish ecology, scientific methods, and interpretation of study results.
1997-1999, Fish Population Dynamics Modeler, NMFS
Develop and apply risk assessment procedures for proposed actions affecting salmon listed under the ESA.
Assist the state and tribal co-managers in the development of recovery and fishery management plans for Puget Sound chinook and coho salmon.
Direct Pacific Salmon Commission Chinook Technical committee assessments of the status and management of U.S. and Canadian west ma chinook stocks.
1996-1997, Quantitative Services Division Manager, NWIFC
Plan, direct, and supervise the activities of division staff.
Develop cutting edge quantitative assessments of natural resource status, present results to policy leaders, and recommend management options.
Direct Pacific Salmon Commission Chinook Technical Committee as discussed above.

Attachment One:

Agency Responses to the Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon

Agencies responding:

Alaska Department of Fish and Game
Columbia River Inter-Tribal Fish Commission
Fisheries and Oceans Canada
National Marine Fisheries Service
Nez Perce Tribal Executive Committee
Northwest Indian Fisheries Commission
Oregon Department of Fish and Wildlife
Pacific States Marine Fisheries Commission
United States Department of the Interior
Washington Department of Fish and Wildlife

STATE OF ALASKA

FRANK H. MURKOWSKI
GOVERNOR

DEPARTMENT OF FISH AND GAME

OFFICE OF THE COMMISSIONER

P.O. BOX 25526
JUNEAU, AK 99802-5526
PHONE: (907) 465-4100
FAX: (907) 465-2332

December 21, 2005

Mr. Don Kowal, Executive Secretary
Pacific Salmon Commission
600 – 1155 Robson Street
Vancouver, B.C. V6E 1B5

Dear Mr. Kowal:

The Alaska Department of Fish and Game welcomes the "Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon." We find it a comprehensive document with many important findings and recommendations that address management and policy issues key to maintaining effective abundance-based conservation and harvest sharing. We agree with the report's statement that "For three decades, the coded wire tag (CWT) system has provided a practical and efficient means for stock- and fishery-specific assessment." We strongly agree that until such time as viable alternatives may be developed and implemented "the CWT system should remain the primary stock assessment tool. . .."

The CWT system has provided the means for an effective abundance-based management approach that provides for conservation while also allowing shared use of the resource. However, the implementation of mass marking of Chinook salmon released from hatcheries and mark-selective fisheries targeting on those fish threatens to undermine the effective conservation programs implemented under the Pacific Salmon Treaty. We look toward identifying means by which we can maintain and improve this system that has worked so well. Toward that end, we recommend that agencies cooperate coast wide to sustain the CWT system by: 1) increasing tagging when and where appropriate; 2) ensuring that sampling of sport and commercial harvests are adequate to accurately estimate stock parameters, such as exploitation rates from CWT recoveries; and 3) providing accurate counts of escapements of both wild and hatchery stocks.

We would like to see the Pacific Salmon Commission (PSC) technical committees, and the technical committees of other West Coast salmon management entities, tasked with working on recommendations on how to maintain and improve the CWT system. In particular, they should look for ways to better account for the harvest of salmon with tags in growing sport fisheries and changing commercial fisheries. The technical committees should also develop standards for marking and sampling that will improve the efficacy of CWT stock identification under current and expected circumstances. Furthermore, the technical committees should look for means to help agencies meet their obligations to effectively count escapements. They may need to look for different ways to collect the information to continue to manage as we have done; but we do not think we should change the basic management approach that has worked so well.

We note that in 1991, when the chairs of the PSC Chinook Technical Committee urged the PSC ". . . to take a strong stand against the use of the adipose fins to mass-mark hatchery-reared chinook and coho," they were making a statement that Alaska supported at that time, and continues to support. Mass marking should be planned and implemented to realize its' benefits and minimize its' associated costs. Therefore, mass marking should be limited to those stocks for which harvest rates can be significantly increased through mark-selective fisheries, and for which there is an associated conservation program that will enable using mass marking to control the interaction of the hatchery stock with naturally reproducing stocks. Consistent with this, we recommend that far north migrating stocks be exempted from congressional (or any other) mandate for mass marking of Chinook from federally-funded programs. These stocks provide limited opportunities for mark-selective fisheries, and adequate programs have not been developed or funded to utilize mass marking to monitor and control hatchery or naturally reproducing brood stocks on the spawning grounds.

We offer the following comments on some specific recommendations from the report:

Recommendation 1: *Substantial improvements must be made in the CWT system to insure that the quality and reliability of collected data are consistent with the increasing demands being placed on these data by fishery managers. Areas requiring attention include quality control/quality assurance, and various sampling design issues, including expansion of catch and escapement samples in areas where little or no sampling currently takes place.*

We suggest that the PSC Coho and Chinook Technical Committees, as well as the Data Sharing committee, make recommendation one a part of their work on an annual basis. Recognizing that in many situations the agency representatives on these committees know best the deficiencies in the CWT data; we urge the committees to work together to identify the problems and find ways to improve the data.

Recommendation 4: *We recommend compilation of a comprehensive survey and statistical analysis of all relevant published and unpublished CWT studies that concern the correspondence between exploitation patterns and rates for hatchery indicator stocks as compared to their natural counterparts. This review should also include new analysis of relevant agency-collected data that have not yet been previously subjected to analysis. Recommendations for additional studies should be made if they are judged necessary.*

We suggest that the PSC Coho and Chinook Technical Committees make recommendation four a part of their work. We also would encourage the Northern and Southern Fund Committees to solicit projects that address this specific issue.

Recommendation 6: *To provide greater assurance that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSFs.*

The treaty has been fashioned to provide different management regimes for fisheries based on the stocks in the area, historical practices, and other considerations. Integral to these fishery plans is the expectation that there will be a level of uncertainty about fishery and stock statistics

that are based on coded wire tag recoveries. We would expect that when fisheries change substantively, e.g., implementation of mark-selective fisheries, that it would be those fisheries that would bear the burden of the compensation for introducing the increased uncertainty, rather than fisheries that remain substantively unchanged. Mark-selective fisheries produce differential fishery impacts on hatchery stocks vs. wild stocks, changing a fundamental premise that the impacts on hatchery stocks can be used as a surrogate for the impacts on the associated wild stocks. This premise has been an integral part of fishery management for decades. To compensate for this and improve management in general, we reiterate that the recommendations in the second paragraph of this document are essential.

Recommendation 12: *We recommend that the Pacific Salmon Commission support an immediate evaluation of a coordinated transition for all salmon species from genetic stock identification (GSI) based on the use of microsatellite markers to GSI based on single nucleotide polymorphism (SNPs) markers. It is important to develop standard sets of species-specific SNPs and related protocols now, so that coast-wide implementation of SNP-based GSI will be cost effective and efficient. The best approach to such a transition is for a multi-jurisdictional agency, such as the PSC, to coordinate broad, multi-agency collaborations such as those adopted during the development of the coast-wide allozyme data bases during the last decade or during the development of the CTC standardized Chinook microsatellite database developed over the last two years. Such collaborative efforts should include provisions for future tissue sample availability from all stocks included, so as to provide for periodic improvement and expansion of the databases.*

We support the use of SNPs as the GSI technique of choice for the PSC and we expect that the capability of this technique will be a reality years before the various labs have sufficient harmony to embrace this approach cooperatively. We cite the Mark Committee as an example of the cooperation and collegial relationship within the CWT community and suggest that genetics labs consider development of some similar relationship to foster open communication, scientific collaboration, and problem solving.

Recommendation 15: *PSC technical committees should explore potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation (or non-landed mortality) rates, but that would still ensure adequate protection for unmarked natural stocks of concern.*

If mark-selective fisheries based on the adipose clip are pursued, we recognize that the differential harvest rate placed on the hatchery stocks will no longer allow for those hatchery stocks to be used as surrogates for similarly situated wild stocks. Thus, for the long-term, alternative models and methods will have to be developed and employed, along with improved estimation of escapements, to understand stock status of the key wild stocks. To prepare for that eventuality, we suggest that an ad hoc committee be formed to analyze alternative approaches and assist with securing funding of the studies of methods that might be employed. The development of alternative fishery models is not something the technical committees should be tasked with; they need to focus on fixing and maintaining the CWT system that is essential for the current management of our fisheries.

One comment not specific to any of the recommendations is as follows:

We wish to clarify what has been characterized as "unwillingness" to conduct electronic sampling in Alaska. This hesitancy stems not only from the high costs and physical impediments of implementation, but also from concerns about the methodology used in electronic sampling and the utility of double index tagged (DIT) groups. We accept that the electronic detection equipment is technically capable of finding coded wire tags at an acceptable rate in the hands of experienced users. However, we believe that the effective electronic sampling is much harder to conduct than visual sampling; our observations in Washington, Canada, as well as anecdotal reports indicate that tags are being missed. We would like to see more validation that samplers will not miss tags with electronic sampling. We question the utility of the DIT groups with Chinook salmon and suspect that this practice will be abandoned. When that happens, the need for sampling unclipped chinook will be significantly lessened if not totally discarded.

Again, we commend the Expert Panel for the report. It is imperative that salmon management agencies coast wide recognize the issues raised in the report, and that there is cooperation on identifying and implementing the steps necessary to ensure that there continues to be statistically reliable data to support fishery management decisions and stock identification programs. We look forward to working within the PSC and in other arenas toward this end.

Sincerely,

David Bedford

David Bedford
Deputy Commissioner

COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION
729 NE Oregon, Suite 200, Portland, Oregon 97232 Telephone 503 238 0667
Fax 503 235 4228

January 9, 2006

Mr. Don Kowal,
Executive Secretary,
Pacific Salmon Commission,
600-1155 Robson Street,
Vancouver, BC V6E 1B5.
January 5, 2006.

Re: Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon.

Dear Mr. Kowal,

On behalf of the Confederated Bands and Tribes of the Yakama Nation, the Nez Perce Tribe, the Confederated Tribes of the Umatilla Indian Reservation and the Confederated Tribes of the Warm Springs Reservation of Oregon, I want to thank the members of the Expert Panel for their report. The members of this Commission support the Report's Peer Reviewed conclusions and recommendations regarding the Future of the Coded Wire Tag Recovery Program for Pacific Salmon.

We recommend that the Pacific Salmon Commission, along with the participating management agencies of the PST process, develop an implementation plan by the end of this current meeting cycle for the Expert Panel Report's Peer Reviewed recommendations, especially the creation of a funding strategy for the "Grand Experiment." We view this implementation plan as a critical step in protecting and conserving our shared salmon resource. It will help ensure the protection of the CWT recovery program as an effective and efficient monitoring and evaluation tool for harvest management programs coastwide, and it is a crucial step in protecting the hundreds of millions of dollars invested in salmon recovery.

The need for this Expert Panel Report regarding the coded wire tag recovery program arose from the unilateral implementation of a mass marking and mark selective fishing program for hatchery produced Chinook and coho salmon. These programs have since been federalized through a legislative rider on federal appropriations bills, without benefit of Congressional hearings or research into the real costs of mass marking and mark selective fishing. The unilateral implementation of a mass marking and mark selective fishing program for hatchery Chinook and coho salmon puts salmon restoration programs and monetary investments in these programs at risk. The tribes, the State of Alaska, and Canada have made their views known on this issue for several years.

The Pacific Salmon Treaty's Memorandum of Understanding (MOU) requires the U.S. and Canada to, among other things, "maintain a coded-wire-tag and recapture program designed to provide statistically reliable data for stock assessment and fishery evaluation." The Pacific Salmon Commission (PSC), the body responsible for implementing the Treaty, has recognized that selective fisheries for marked hatchery coho and Chinook salmon can impact the coastwide coded wire tag (CWT) program. The tribes, states, and federal fishery agencies have invested an extensive amount of money and effort into the various components of the coded wire tag program. It is evident that, despite some short-comings of the system, the current system is the only available means of monitoring and evaluating the harvest management annexes of the Pacific Salmon Treaty (PST). It is also obvious that the unilateral implementation of mass marking and mark selective fishing programs undermines the continued viability of this management tool.

The recognition of the inherent and costly problems of utilizing the adipose fin clip as a visual mark for mark selective fishing for hatchery produced salmon is not a concern recently identified; technical concerns and issues regarding the impact of clipping the adipose fin as a visual marker for mark selective fishing were identified as a critical issue nearly fifteen years ago:

> The Chinook Technical Committee (CTC) discussed the proposal and is strongly opposed to the use of adipose clips to mass-mark hatchery fish. This practice would render the CWT program nearly useless as a management tool. (CTC 1991)

Since then, we have learned that the costs and problems associated with the unilateral implementation of mass marking and mark selective fishing, especially for Chinook salmon stocks, are worse than those predicted by the CTC in 1991.

Comments regarding specific Findings and Recommendations

The Columbia River treaty tribes agree that, as stated in the report, the only tools currently available for estimating age and fishery specific exploitation rates on individual stocks are through the use of CWTs. As stated clearly in ***Finding 1***: "*There is no obvious viable short-term alternative to the CWT system that could provide the data required for cohort analysis and implementation of PST management regimes for coho and Chinook salmon*".

Regarding problems with the existing tag recovery programs, we support most of the Expert Panel's findings. In addition, with regard to ***Finding 5***, the Columbia River Treaty Tribes are one of the only parties involved in the PSC process that have verified the assumptions of using a hatchery indicator tag program (Priest Rapids Hatchery) to represent a natural stock component (Upriver Bright, URB Chinook). The tribes now have a time series of replicate tag groups from the natural component of Hanford Reach fall Chinook. The results indicate that the hatchery and natural groups have similar patterns of exploitation at age.

Regarding the implementation of mark-selective fisheries on Chinook, the Columbia River Treaty Tribes are not optimistic about the implementation of mark selective fisheries as a tool to protect stocks of concern. The Expert Panel's Report appears to support these concerns. There

are a number of unknowns involved with mark selective fisheries. However optimistic the proponents of these harvest management tools may be on these unknowns, we remain unconvinced of the practical implementation of these types of fisheries. I want to emphasize that the tribes have long used *selective* fisheries, such as time and area restrictions, gear restrictions, and voluntary fishery closures as conservation measures to protect weak stocks and we will continue to use such effective tools. In contrast, we view mark-selective fisheries simply as a tool to target hatchery produced fish, and therefore support status quo hatchery production practices, not conservation.

The primary issue of concern is maintaining the viability of the CWT program for its multiple purposes, including conservation. Mark-selective fisheries are likely to bias the exploitation rates that are derived from the CWT recoveries. Due to intensive efforts directed to marked stocks, the unmarked recoveries estimated in these models are inaccurate and biased low. In a workshop jointly held by Washington Department of Fish and Wildlife (WDFW) and the tribes in October 1999, it was pointed out that:

> *"BPERs (Base Period Exploitation Rates) are estimated from CWT data collected under conditions where all legal fish brought to the vessel are assumed to be retained. A fish was encountered only once; when it was caught, it was removed from the population. Under mark-selective fisheries, an unmarked fish is supposed to be released. Some of the unmarked fish will die, others survive and will become susceptible to recapture again. When discrete equations are used to model impacts of mark-selective fisheries on unmarked fish, this potential for multiple recapture during a model time period is ignored. Drop off and release mortality are underestimated and exploitation rates are biased low as a result. The likelihood of recapture will increase the longer the time period represented in discrete models (the time strata commonly modeled is monthly for coho, quarterly or yearly for chinook). The higher the exploitation rate, the greater the bias".*

The Selective Fishery Evaluation Committee's Analytical Work Group (SFECAWG), established by the PSC, has investigated several methods (SFEC 2002) to address these biases and develop estimates of harvest impacts that are comparable to the current CWT system. Although a couple of theoretical approaches have been outlined, in reality these systems may not prove to be practical (JCDAW 2003). This has been reiterated in the report of the expert panel in ***Findings 7 and 8, 9 and 10***, where the practical limitations of the Double Index Tag (DIT) program are discussed.

An issue that remains unresolved by the SFEC is correcting for multiple encounter bias. Simulations performed by our staff and others (Lawson and Sampson 1996, Zhou 2002), show that there are a higher incidence of unmarked mortalities than the management models predict. These estimates are directly related to the duration of the marked selective fisheries. In addition, the impacts increase non-linearly when unmarked stocks are at critically low abundances (an issue that is pertinent to some of the Snake River stocks).

While a number of technologies are being developed as potential replacements for the CWT system, it is premature to assume that a coast-wide sampling system for these technologies can

be implemented in the same manner as for the CWT system. While ***Findings 18 and 19*** suggest that new technologies show potential in identifying stocks, we believe substantial research needs to be conducted before we proceed down that route. It is clear from ***Findings 12 through 16*** that technologies such as allozymes, micro-satellite markers or SNPs in Genetic Stock Identification (GSI) techniques have numerous logistical limitations and cannot entirely replace the CWT system.

In addition as pointed out in ***Finding 12:*** *" Although such combination of technologies may be theoretically possible, their combined use could have substantial increased costs and would require a degree of interagency coordination and collaboration that exceeds that which was necessary to develop the CWT system."* The practical limitations imposed by the costs and co-ordination between agencies implementing these new technologies may be extremely difficult to overcome and we think we should be extremely cautious before disregarding the CWT system that is currently in place.

The tribes believe that the region must carefully consider how the GSI technology will fit into current management issues. At the very least, the Pacific Salmon Commission should plan to work on GSI technologies in very close coordination with our current CWT system. In particular, we are not sure how ***Recommendations 12, 13 and 14*** would be implemented. The first step is to work out issues of sampling, coordination and assignment errors in these GSI techniques as stated in ***Findings 12 through 16***.

In addition, with regards to ***Recommendation 7*** and ***Table 4***, the tribes are unclear as to what the appropriate methods for an intended mark selective fishery is supposed to convey, other than the need to develop more intensive sampling methodologies when mark selective fisheries are prosecuted by an agency. It is clear from Zhou (2002), JCDAW (2003) and ***Findings 7 through 10*** that mark-selective fisheries (MSF) will result in a loss in precision as far as exploitation rates are concerned, regardless of any method identified. The tribes continue to hope that the agencies involved will be cautious about implementing an untested method of fishing.

Thus we strongly agree with ***Recommendation 6:*** *"To provide greater assurance that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSFs."* The tribes believe the MSF proposing agency that causes this increased uncertainty should bear the burden and incur the largest reduction in the overall exploitation rate in order to guarantee that the conservation objectives are met for that stock.

As far as direction the PSC should take regarding this report, we strongly support ***Recommendation 8:*** *"The PSC should explore the interest of fishery agencies in participating in a Grand Experiment to improve the basis for harvest management decisions coast-wide through an intensive program conducted over a short period of time."* If interest is sufficient, the various PSC technical committees (Chinook, Coho and Selective Fishery Evaluation) could prepare the specifications of the experiment, including addressing the feasibility and the experimental design. Implementation and funding regarding this experiment could be made available through the Northern and Southern Funds as well as from external sources such as National Science

Foundation (NSF) or National Research Council (NRC), and other private sources. Finally, if such an undertaking did proceed oversight on analyzing these results should rest with those specific technical committees.

Finally, our staff is already working on issues related to ***Recommendation 4***, including making a presentation to that effect in **Western Division AFS meeting in San Diego in 2003.** Our staff is also currently working on issues related to ***Recommendation 5.***

In conclusion, the tribes reiterate that experimental results on mark selective fishing on Chinook and coho, to date, have given a very wide range of results. It is premature to assume that all the findings and recommendations will be addressed soon, and it is premature to assume that mark selective fisheries are indeed the appropriate management tool for rebuilding depressed stocks. Again, it is important to remember that mark selective fisheries were proposed and are now being used not as tool to conserve weak and rebuilding salmon stocks, but merely as a tool that would allow hatchery fish to be caught – and allow hatchery production programs to remain unchanged, even though an obvious need exists to change hatchery production programs in order to aid in the restoration and rebuilding of salmon stocks.

Mark selective fisheries should not be implemented in the future until all of the issues identified in the peer reviewed Expert Panel Report are resolved through the agreement of the tribes, states, and federal fishery agencies. Unfortunately we again sense that some parties are rushing into the utilization of mark selective fisheries without taking the time for serious consideration of the possible negative effects. More effort should be paid to the other components for recovery of depressed or endangered populations, namely through the use of supplementation programs, habitat conservation and restoration programs, and hydropower system and flood control modifications; these efforts which would address the underlying problems limiting salmon production and productivity in a much better way than mark selective fisheries.

I look forward to working with you, members of the Pacific Salmon Commission and with the tribes, states and federal fishery management agencies to develop an implementation plan for the recommendations provided by the Expert Panel.

Sincerely,

Olney Patt, Jr.

Olney Patt
Executive Director

References

CTC. 1991. Letter from CTC Co-Chairs to the Chair and Vice-Chair of the Pacific Salmon Commission regarding the de-sequestration of the adipose fin clip as a marker for the coded wire tag. *See* Pacific Salmon Commission's Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon. November 2005.

JCDAW (Joint Coho DIT Analysis Workgroup). 2003. Analysis of Coho Salmon Double Index (DIT) Data for the Brood Years 1998-2000. Northwest Fishery Resource Bulletin Project Report Series No. 12. Olympia, Washington, USA.

Lawson, P. and Sampson, D. 1996. Gear-Related Mortality in selective Fisheries for Ocean Salmon. North American Journal of Fisheries Management 16: 512-520.

SFEC. 2002. Investigation of methods to estimate mortalities of unmarked salmon in mark selective fisheries through the use of double index tag groups. TCSFEC (02)-1. pp. 87.

Zhou, S. 2002. Uncertainties in estimating fishing mortality in unmarked salmon in mark-selective fisheries using double-index tagging. North American Journal of Fisheries Management 22: 480-493.

Fisheries and Oceans
Pêches et Océans

Pacific Region
Suite 200 - 401 Burrard Street
Vancouver, B.C.
V6C 3S4

Région du Pacifique
Pièce 200 - 401 rue Burrard
Vancouver (C.-B.)
V6C 3S4

Your file Votre référence

Our file Notre référence

FEB 0 3 2006

Mr. Don Kowal
Executive Secretary
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, BC, V6E 1B5

Dear Mr. Kowal

On behalf of Fisheries and Oceans Canada, I would like to express appreciation to Dr. Dave Hankin and the Expert Panel for their clear and thoughtful report. We acknowledge the hard work required to review and synthesize the material on this complex subject. The report suggests that we are on the verge of new technology in some areas, demonstrating the Panel's innovation and foresight.

I would like to begin by acknowledging the major findings and issues around the CWT program. For example:

- Finding 1: "the CWT system is the only technology that is currently capable of providing the data required by the PSC…"
- Finding 6: "The Panel concurs with previous ASTEC findings that Mass Marking and Mark-selective Fisheries together pose a serious threat to the integrity of the CWT recovery data systems."
- Finding 11: "Some existing technologies can complement the existing CWT system."
- And several findings that lead to Recommendation 15: "PSC technical committees should explore potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation rates…"

These findings present a serious challenge for agencies associated with the Pacific Salmon Commission (PSC). The CWT system is the only technology capable of meeting the information requirements of the current Pacific Salmon Treaty (PST) chinook and coho management regimes. Even when issues of restored capacity and co-operation are addressed, the development of mass-mark selective fisheries along with increasing demands for greater resolution of fisheries (time, area, gear strata) will augment the data limitations, uncertainty and costs for the CWT

Canada

program. While new methodologies may complement the CWT program, the Expert Panel notes sampling limitations (e.g., the 'needle in the haystack' scenario for depressed natural populations), the extensive costs anticipated, and the need for continued methodological development.

I would also like to suggest a few issues in the report that might require further reflection. For example:

- Finding 16: the wording around AABM should be considered in light of the Pacific Salmon Treaty Annex language and the obligations that the parties made in the 1999 Agreement.
- Recommendation 12: the supporting documentation includes the Panel's conclusion that "future applications of genetic methods for salmon management should employ SNP markers". This statement appears inconsistent with the CSC report: "Where good microstatellite baselines are available, the CSC encourages their continued use in the near term and at the same time development and evaluation of SNPs for future use."
- Overall, implementation of the report will require a high level of coordination and cooperation amongst the agencies involved.

Given the complexity and magnitude of these issues, DFO intends to reflect further and to provide detailed comments on each recommendation at a later date. At the same time, I recognize the urgency expressed in the report to make changes to the CWT system and would support moving ahead in those areas where we can find an early consensus. In other areas we may need further work to understand fully the potential impacts (including the costs) around implementation of the recommendations and the suggested next steps before proceeding.

I look forward to our progress and continued collaboration on this important topic.

Sincerely,

Paul Sprout
Regional Director General
Fisheries and Oceans Canada

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
7600 Sand Point Way N E., Bldg. 1
Seattle, WA 98115

December 16, 2005

Don Kowal
Executive Secretary
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, BC V6E 1B5
Canada

Dear Mr. Kowal

Thank you for sending us the Expert Panel's final report on the future of the coastwide coded wire tagging program. NOAA Fisheries greatly appreciates the Pacific Salmon Commission's leadership in addressing this issue, as it is critical that a scientifically credible approach to monitoring fishery impacts and the status of salmon stocks be coordinated among the many jurisdictions involved in managing this precious resource.

This is an especially challenging undertaking given the advent of mass marking, mark selective fisheries, and the requirement of fishery management to address the biological requirements of depressed, threatened and endangered salmon populations.

As the U.S. government agency responsible for administering the Endangered Species Act (ESA) for listed salmon and steelhead species, NOAA Fisheries recently issued federal regulations that exempt ESA listed hatchery fish with an adipose fin clip from the take prohibitions promulgated under the ESA. This regulation reflects our interest in supporting sustainable fisheries while providing a means to limit fishery impacts on listed natural origin fish. We anticipate that this regulation will be in effect for some time, which underscores the need for a coordinated approach to mitigating the effect of mass marking and mark selective fisheries on our collective monitoring programs.

Rather than provide specific comments on the substance of the report at this time, NOAA Fisheries will provide its comments and inputs as discussions and actions occur on potential implementation of the findings and recommendations. The ESA requires NOAA Fisheries to consult on any action that may adversely affect ESA listed salmon and steelhead, and we will undertake that responsibility as proposals are developed to implement the recommendations in the Expert Panel report. In addition, NOAA Fisheries is undertaking a renewed review of salmon harvest exploitation rates relative to recovery needs of ESA listed salmon and steelhead populations. We will be looking in particular at harvest standards for consistency with Recovery Plans. As you may know,

Printed on Recycled Paper

NOAA Fisheries recently approved a proposed Recovery Plan for Puget Sound Chinook, and we expect to have proposed recovery plans in place for all other ESA listed salmon in the very near future.

Again, thank you and the Commission for taking on this important issue.

Sincerely,

for D. Robert Lohn
Regional Administrator

Nez Perce

TRIBAL EXECUTIVE COMMITTEE
P.O. BOX 305 • LAPWAI, IDAHO 83540 • (208) 843-2253

January 17, 2006

Mr. Don Kowal
Executive Secretary,
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, BC V6E 1B5

RE: Report of the Expert Panel on the future of the Coded Wire Tag Recovery Program for Pacific Salmon.

Dear Mr. Kowal:

On behalf of the Nez Perce Tribe, I want to thank the members of the Expert Panel for their report. Our Tribe support the Report's Peer Reviewed conclusions and recommendations regarding the future of the coded wire (CWT) tag recovery program for pacific salmon.

We recommend that the Pacific Salmon Commission, along with the participating management agencies of the Pacific Salmon Treaty (PST) process, develop an implementation plan by the end of this current meeting cycle for the Expert Panel Report's Peer Reviewed recommendations, especially the creation of a funding strategy for the grand experiment. We view this implementation plan as a critical step in protecting and conserving our shared salmon resource. It will help ensure the protection of the CWT recovery program as an effective and efficient monitoring and evaluation tool for harvest management programs coastwide, and it is a crucial step in protecting the hundreds of millions of dollars invested in salmon recovery.

The need for this Expert Panel Report regarding the CWT recovery program arose from the unilateral implementation of a mass marking and mark selective fishing program for hatchery produced Chinook and Coho salmon. These programs have since been federalized through a legislative rider on federal appropriations bills, without benefit of Congressional hearings or research into the real costs of mass marking and mark selective fishing. The unilateral implementation of a mass marking and mark selective fishing program for hatchery Chinook and Coho salmon puts salmon restoration programs and monetary investments in these programs at risk. Indian Tribes, the State of Alaska, and Canada have made

their views known on this issue for several years.

The PST Memorandum of Understanding (MOU) requires the United States and Canada to, among other things, "maintain a coded wire tag and recapture program designed to provide statistically reliable data for stock assessment and fishery evaluation". The Pacific Salmon Commission (PSC), the body responsible for implementing the PST, has recognized that selective fisheries for marked hatchery Chinook and Coho salmon can impact the coastwide CWT program. The Nez Perce Tribe, several states along with other federal agencies have invested an extensive amount of money and effort into the various components of the CWT program. It is evident that, despite some shortcomings of the system, the current system is the only available means of monitoring and evaluating the harvest management annexes of the PST. It is also obvious that the unilateral implementation of mass marking and mark selective fishing programs undermines the continued viability of this management tool.

The recognition of the inherent and costly problems of utilizing the adipose fin clip as a visual mark for mark selective fishing for hatchery produced salmon is a concern that has not just been recently identified; technical concerns and issues regarding the impact of clipping the adipose fin as a visual marker for mark selective fishing were identified as a critical issue nearly fifteen years ago:

> The Chinook Technical Committee (CTC) discussed the proposal and is strongly opposed to the use of adipose clips to mass mark hatchery fish. This practice would render the CWT program nearly useless as a management tool. (CTC 1991)

Since then, we have learned that the costs and problems associated with the unilateral implementation of mass marking and mark selective fishing, especially for Chinook salmon stocks, are worse that those predicted by the CTC in 1991.

COMMENTS REGARDING SPECIFIC FINDINGS AND RECOMMENDATIONS

The Nez Perce Tribe agree that, as stated in the report, the only tools currently available for estimating age and fishery specific exploitation rates on individual stocks are through the use of CWTs. As stated clearly in Finding 1: "There is no obvious viable short term alternative to the CWT system that could provide that data required for cohort analysis and implementation of PST management regimes for Chinook and Coho salmon".

Regarding problems with the existing tag recovery programs, we support most of the Expert Panel's findings. In addition, with regard to Finding 5, the Nez Perce Tribe is only one of the parties involved in the PSC process that have verified the assumptions of using a hatchery indicator tag program (Priest

Rapids Hatchery) to represent a natural stock component (Upriver Bright, URB Chinook). All of the parties now have a time series of replicate tag groups from the natural component of Hanford Reach fall Chinook. The results indicate that the hatchery and natural groups have similar patterns of exploitation.

Regarding the implementation of mark selective fisheries on Chinook, the Nez Perce Tribe are not optimistic about the implementation of mark selective fisheries as a tool to protect stocks of concern. The Expert Panel's Report appears to support these concerns. There are a number of unknowns involved with mark selective fisheries. However optimistic the proponents of these harvest management tools may be on these unknowns, we remain unconvinced of the practical implementation of these types of fisheries. I want to emphasize that our Tribe have long used selective fisheries, such as time and area restrictions, gear restrictions and voluntary fishery closures as conservation measures to protect weak stocks and we will continue to use such effective tools. In contrast, we view the proposed mark selective fisheries simply as a tool to target hatchery produced fish, and therefore support status quo hatchery production practices, not conservation.

The primary issue of concern is maintaining the viability of the CWT program for its multiple purposes, including conservation. Mark selective fisheries are likely to bias the exploitation rates that are derived from the CWT recoveries. Due to intensive efforts directed to marked stocks, the unmarked recoveries estimated in these models are inaccurate and biased low. In a workshop jointly held by the Washington Department of Fish & Wildlife (WDFW) and the Columbia River Tribes in October of 1999, it was pointed out:

> "Base Period Exploitation Rates (BPER's) are estimated from CWT data collected under conditions where all legal fish brought to the vessel are assumed to be retained. A fish was encountered only once; when it was caught, it was removed from the population. Under marked selective fisheries, an unmarked fish is supposed to be released. Some of the unmarked fish will die, others survive and will become susceptible to recapture again. When discrete equations are used to model impacts of mark selective fisheries on unmarked fish, this potential for multiple recapture during a model time period is ignored. Drop off and release mortality are underestimated and exploitation rates are biased low as a result. The likelihood of recapture will increase the longer the time period represented in discrete models (the time strata commonly modeled is monthly for Coho, quarterly or yearly for Chinook). The higher the exploitation rate, the greater the bias."

The Selective Fishery Evaluation Committee's Analytical Group

(SFECAWG), established by the PSC, has investigated several methods (SFEC 2002) to address these biases and develop estimates of harvest impacts that are comparable to the CWT system. Although a couple of theoretical approaches have been outlined, in reality these systems may not prove to be practical (JCDAW 2003). This has been reiterated in the report of the expert panel in **Findings 7, 8 and 10**, where practical limitations of the Double Index Tag (DIT) program are discussed.

An issue that remains unresolved by the SFEC is correcting for multiple encounter bias. Simulations performed by the Columbia River Inter-Tribal Fish Commission (CRITFC) staff and others (Lawson and Sampson 1996, Zhou 2002), show that there are a higher incidence of unmarked mortalities than the management models predict. These estimates are directly related to the duration of the marked selective fisheries. In addition, the impacts increase non-linearly when unmarked stocks are at critically low abundances (an issue that is pertinent to some of the Snake River stocks).

While a number of technologies are being developed as potential replacements for the CWT system, it is premature to assume that the coastwide sampling system for these technologies can be implemented in the same manner as for the CWT system. While **Findings 18 and 19** suggest that the new technologies show potential in identifying stocks, we believe substantial research needs to be conducted before we proceed down that route. It is unclear from **Findings 12 through 16** that technologies such as allozymes, micro-satellite markers or SNP's in Genetic Stock Identification (GSI) techniques have numerous logistical limitations and cannot entirely replace the CWT system.

In addition as pointed out in **Finding 12**: "Although such combination of technologies may be theoretically possible, their combined use could have substantial increased costs and would require a degree of interagency coordination and collaboration that exceeds that which was necessary to develop the CWT system". The practical limitations imposed by the costs and coordination between agencies implementing these new technologies may be extremely difficult to overcome and we think we should be extremely cautious before disregarding the CWT system that is currently in place.

Our Tribe believes that the region must carefully consider how the GSI technology will fit into current management issues. At the very least, the PSC should plan to work on GSI technologies in very close coordination with our current CWT system. In particular, we are not sure how **Recommendations 12, 13 and 14** would be implemented. The first step is to work out issues of sampling, coordination and assignment errors in these GSI techniques as stated in **Findings 12 through 16**.

In addition, with regards to **Recommendation 7 and Table 4**,our Tribe is unclear as to what the appropriate methods for an intended mark selective fishery is supposed to convey, other than the need to develop more intensive sampling methodologies when mark selective fisheries are prosecuted by an agency. It is clear from Zhou (2002), JCDAW (2003) and **Findings 7 through 10** that mark selective fisheries (MSF) will result in a loss in precision as far as exploitation rates are concerned, regardless of any method identified. Our Tribe continues to hope that the agencies involved will be cautious about implementing an untested method of fishing.

Thus we strongly agree with **Recommendation 6**: "To provide greater assurances that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSF's". The Nez Perce Tribe believe the MSF proposing agency that causes this increased uncertainty should bear the burden and incur the largest reduction in the overall exploitation rate in order to guarantee that the conservation objectives are met for that stock.

As far as direction the PSC should take regarding this report, we strongly support **Recommendation 8**: "The PSC should explore the interest of fishery agencies in participating in a Grand Experiment to improve the basis for harvest management decisions coastwide through an intensive program conducted over a short period of time". If interest is sufficient, the various PSC technical committees (Chinook, Coho and Selective Fishery Evaluation) could prepare the specifications of the experiment, including addressing the feasibility and the experimental design. Implementation and funding regarding this experiment could be made available through the Northern and Southern Funds as well as from external sources such as the National Science Foundation (NSF) or the National Research Council (NRC), and other private sources. Finally, if such an undertaking did proceed, oversight on analyzing these results should rest with those specific technical committees.

Finally, CRITFC staff and our Tribe is already working on issues related to **Recommendation 4**, which included making a presentation at the **Western Division AFS meeting in San Diego, CA** in 2003. We are also working with CRITFC staff on issues related to **Recommendation 5**.

In conclusion, we want to reiterate that experimental results on mark selective fishing on Chinook and Coho, to date, have given a very wide range of results. It is premature to assume that all the findings and recommendations will be addressed soon, and it is premature to assume that mark selective fisheries are indeed the appropriate management tool for

rebuilding depressed stocks. Again, it is important to remember that mark selective fisheries were proposed and are now being used not as a tool to conserve weak and rebuilding salmon stocks, but merely as a tool that would allow hatchery fish to be caught - and allow hatchery production programs to remain unchanged, even though an obvious need exists to change hatchery production programs in order to aid in the restoration and rebuilding of wild salmon stocks.

Mark Selective Fisheries should not be implemented in the future until all of the issues identified in the peer reviewed Expert Panel Report are resolved through the agreement of the Tribes, States and the Federal Fishery Agencies. Unfortunately we again sense that some parties are rushing into the utilization of mark selective fisheries without taking the time for serious consideration of the possible negative effects. More effort should be paid to the other components for recovery of depressed or endangered populations, namely through the use of supplementation programs, habitat conservation and restoration programs, and hydropower system and flood control modifications; these efforts which would address the underlying problems limiting salmon production and productivity in a much better way than mark selective fisheries.

The Nez Perce Tribe looks forward to working with you, the members of the PSC and with the other Tribes, States and Federal Fishery management agencies to develop an implementation plan for the Recommendations provided by the Expert Panel Report.

Thank you.

Sincerely,

Rebecca A. Miles, Chairman
Nez Perce Tribal Executive
Committee

Attachment

Attachment (Letter to Mr. Don Kowal)

"REFERENCES"

CCT. 1991. Letter from CTC Co-Chairs to the Chair and Vice Chair of the Pacific Salmon Commission regarding the de-sequestration of the adipose fin clip as a marker for the coded wire tag. See Pacific Salmon Commission's Report of the Expert Panel on the future on the Coded Wire Tag Recovery Program for Pacific Salmon. November 2005.

JCDAW (Joint Coho DIT Analysis Workgroup). 2003. Analysis of Coho Salmon (DIT) Double Index Data for the Brood Years 1998-2000. Northwest Fishery Resource Bulletin Project Report Series No. 12. Olympia, Washington, USA.

Lawson, P. and Sampson, D. 1996. Gear-Related Mortality in selective fisheries for Ocean Salmon. North American Journal of Fisheries Management: 512-520

SFCE. 2002 Investigation of methods to estimate mortalities of unmarked salmon in mark selective fisheries through the use of double index tag groups. TCSFEC (02)-1. pp 87.

Zhou, 2002. Uncertainties in estimating fishing mortality in unmarked salmon in mark selective fisheries using double index tagging. North American Journal of Fisheries Management 22: 480-493.

Northwest Indian Fisheries Commission
6730 Martin Way E., Olympia, Washington 98516-5540
Phone (360) 438-1180 www.nwifc.org FAX # 753-8659

December 14, 2005

Mr. Don Kowal
Executive Secretary
Pacific Salmon Commission
600 – 1155 Robson Street
Vancouver, B.C. V6E 1B5

RE: Pacific Salmon Commission – Final Report of the Expert Panel regarding the Coded Wire Tag Program

Dear Mr. Kowal Don

We would like to express our thanks to Dr. Hankin and the other members of the Expert Panel for their detailed and thorough review of the Coded Wire Tag (CWT) Program. The western Washington Tribes appreciate the effort that they put into examining the CWT Program, the challenges its faces, the new and emerging technologies that are available, and their recommendations to the Commission and its participating entities.

It is now incumbent upon the Commission and its participating entities to give serious consideration to each of the recommendations from the Expert Panel. Our hope is that an action plan to do just that can be developed and adopted by the Commission before the end of the upcoming meeting cycle.

The CWT program has provided a practical, efficient and cost-effective means for stock- and fishery-specific assessments. The Pacific Salmon Commission's management regimes for chinook and coho salmon rely extensively on data from this program. We concur with the Expert Panel's findings that there has been degradation to the coastwide program. It is time for all the involved entities to re-affirm their commit to the CWT Program and undertake an in-depth review of the procedures and methods involved in collecting and reporting CWT data. The quality and reliability of the data collected within this program must be improved as it will remain the primary stock assessment tool for at least the next 5-10 years, regardless of advancements in other technologies.

A renewed commitment to the CWT Program must also translate into cooperative action to address issues presented by mass marking and mark-selective fishing. We share the same concerns as the Expert Panel regarding impacts from these activities on the CWT Program. The Panel's recommendations regarding mass-marking and mark-selective fisheries should serve as the starting point for Commission deliberations. Collectively, as responsible fishery managers, we must begin to explicitly consider the uncertainty

stemming from these activities in the development of our harvest management plans. An action plan must be developed that includes an approach that links marking, tagging and analytical methods to the anticipated intensity of mark-selective fisheries.

The Expert Panel's recommendations for a coordinated research and implementation plan contain a variety of viable options for alternate technologies. These options will need to be weighed carefully as research funds are limited. This is the one section within the report that caused us concern. We do not dispute the potential benefits that Single Nucleotide Polymorphism (SNP) markers may hold for future salmon research. However, we do believe there has been a general overstatement of the current state of the art with regard to SNPs as apposed to microsatellites. Substantial advancement with the technology will need to occur before SNP assays will be able to identify closely affiliated natural populations. Even though mircosatellite technology has been employed for time now, this technology is still not able to identify these closely affiliated populations. While we are not vested in either technology, the Panel should clarify the current capability of each approach.

In summary, we agree with the Expert Panel that the CWT program needs a tune-up. We are supportive of their recommendations and schedule of implementation steps to accomplish this important task. We remain committed to the CWT Program and look forward to working with the Commission and its participating entities on developing an action plan to accomplish this task.

Sincerely,

Michael Grayum
Executive Director

Oregon
Theodore R. Kulongoski, Governor

Department of Fish and Wildlife
Office of the Director
3406 Cherry Avenue, NE
Salem, OR 97303
503.947.6044
FAX 503.947.6042
TTY 503.947.6339
www.dfw.state.or.us

February 2, 2006

Mr. Don Kowal
Executive Secretary
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, B.C., V6E 1B5

Dear Mr. Kowal:

Thank you for the opportunity to comment on the "Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon". The Oregon Department of Fish and Wildlife (ODFW) appreciates the time, thought and work contributed by the Expert Panel (EP) to produce this report, and agree with much of the substance and recommendations in the document. It is our hope that work will proceed to address many of the challenges to the current Coded Wire Tagging (CWT) program, with foresight for ever-changing fisheries, their management and the identification of contributing salmon stocks.

Overall, we support the corrective measures to address current deficiencies in the CWT program as outlined in the EP Report. ODFW will continue to support the efforts of the Pacific Salmon Commission (PSC) and technical committees to improve analytical methods compromised by the increasing complexity of the CWT program and implementation of Mass Marking (MM) and Mark Selective Fisheries (MSF).

The CWT program has provided a framework for the assessment of salmon stocks and their management for the past three decades. The EP has done a comprehensive job in detailing the current and emergent challenges for the CWT program to continue to supply the needed information for a viable harvest management scheme, as well as exploring new alternatives for generation of the needed information. We concur with the EP that the CWT System is the only reasonable management alternative for the short term (5-10 years) to provide for the needs of both the treaty and local management agencies. New technologies for the identification of specific stocks seem to hold promise and should be further pursued, however, we must work to improve the current system for the timebeing.

Specific comments on the EP findings and recommendations are as follows:

Finding 7: We have concerns about the demands and relevancy of expansion of Double Index Tagging (DIT) groups given impacts on sampling programs and methodology issues raised that question whether DIT can meet PSC requirements to estimate age- and fishery-specific exploitation rates (Finding 8).

Recommendations 1-5: We support all of these recommendations that are designed to correct current deficiencies in the CWT system. Consistent with Recommendation 4, ODFW tagged (Ad+CWT) wild fall chinook on the Siuslaw River in 2002 to determine the adequacy of use of the Salmon River Hatchery stock as the Exploitation Rate Indicator for North Oregon Coast aggregate chinook stocks.

Recommendation 6: ODFW's Mark Selective Fisheries are already consistent with this recommendation. We have conducted limited MFS's since 1999 designed to meet very specific conservation objectives for coho and chinook.

Recommendation 7: We support an approach similar to the example presented in which tagging and analytical methods are linked to the anticipated intensity of MSF. It is our understanding that the Selective Fishery Evaluation Committee (SFEC) will develop the specific methodologies to implement this approach.

Recommendation 8: The PSC should explore the interest of fishery agencies in participating in a "Grand Experiment" to improve the basis for harvest management decisions coastwise. The recommendation may have merit, but needs to be further developed by PSC technical committees.

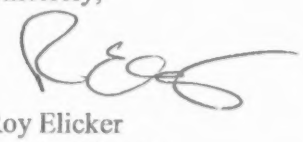
Recommendation 9: The PSC should consider follow-up discussions or workshops to facilitate application of new and improved technologies for the CWT program.

Recommendation 10: We support assigning the bi-lateral SFEC to search available literature and agency information relative to mortality rates of alternative marks compared to adipose clips and determine whether additional experiments should be conducted on use of alternative external marks.

Recommendation 12: We recognize that this issue is still under debate within the genetics community, and do not presume to interject comment as to the appropriateness of either technology at this time. However, we are aware of the use of a blend of both technologies, and their utility in stock identification in other mixed-stock fisheries (e.g. Bristol Bay Sockeye). While the continued advancements in single nucleotide polymorphism (SNPs) technology is promising, it would seem ill-advised to abandon the substantial investment already made in the development of microsatellite markers and their proven record in stock identification. We assert, therefore, that consideration be made to develop a melding of current and emergent genetic methods (microsatellite, SNPs, and Full Parental Genotyping) to provide for the stock identification needs of current and future fishing regimes.

Again, we compliment the Expert Panel for their comprehensive effort that will lead to improvements in the CWT program and other tools for fishery management. We recognize the importance of a collaborative approach to the implementation of the necessary changes, and stand ready to contribute with the PSC toward practical solutions for the challenges before us.

Sincerely,



Roy Elicker
Interim Director

C: Rollie Rousseau
Burnie Bohn
Curt Melcher

PACIFIC STATES MARINE FISHERIES COMMISSION
205 S.E. SPOKANE STREET, SUITE 100, PORTLAND, OREGON 97202
PHONE (503) 595-3100 FAX (503) 595-3232

Mr. Don Kowal
Executive Secretary
Pacific Salmon Commission
600 – 1155 Robson Street
Vancouver, B.C. V6E 1B5
Canada

14 December, 2005

Dear Mr. Kowal,

Thank you for the opportunity to comment on the final "Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon". The Expert Panel is to be commented for their excellent work. They have provided a solid analysis of the impact of Mass Marking (MM) and Mark Selective Fisheries (MSFs) on the coastwide CWT system, along with excellent recommendations for improvements, in addition to a much needed evaluation of the capacity of other technologies to provide the requisite data to evaluate chinook and coho salmon populations.

1) CWT System Still Viable in Many Important Ways

The coastwide CWT system is remarkable for its longevity (35+ years), size of tagging and sampling programs, and for the mutual cooperation of all tagging and recovery agencies along the entire west coast of North America. There are of course flaws and shortcomings, several of which have been exacerbated by the growing role of MM and MSFs since 1997, and highlighted in this report. And yet, it is important to recognize that the current CWT program continues to be functional for a wide variety of fishery management needs, including evaluation of enhancement programs, conducting comparative experiments, monitoring ocean survival, providing certain types of data for fishery models, and evaluation of stock status.

2) Inability to Estimate Mortality of Unmarked and Non-Retained Fish in MSFs not Limited to CWT System

The one overarching flaw of the CWT program is that it can not provide required exploitation rates of unmarked fish hooked and released in MSFs. As noted in the report, MSFs violate the basic assumption that the tagged to untagged ratio of a tagged stock remains constant during its migration cycle. Instead, tagged hatchery fish (CWT + adipose clip) are retained in a MSF, while the unmarked natural fish (adipose fin intact) must be released if hooked. As such, the CWT marked hatchery fish can't serve as surrogates for evaluating stock-age-fishery exploitation rates on unmarked fish not retained in the catch under MSFs.

The Expert Panel did an excellent job in describing several new technologies (i.e. otolith thermal marking, genetic stock identification (GSI), or Radio Frequency Identification tags (RFID) tags)

that potentially could replace the CWT system within 5-10 years. PSMFC endorses this effort to plan for the future! However, by the same token, we wish to also highlight the point made in the report that these alternative marking technologies will not solve the problem of determining specific exploitation rates in unmarked fish taken and then released in a MSF. Regardless of the stock identification technology used, the release of unmarked fish in a MSF negates the ability to measure the exploitation rate on natural fish impacted by that fishery. Hence, a cautionary note that adoption of any new technology in the future must be done carefully, and with the clear understanding that this key flaw in the CWT system will not be fixed by moving to a new stock identification technology.

3) Quality Control/Quality Assurance Issues

The Expert Panel also highlighted the need for substantial improvements in the quality and reliability of collected CWT data. PSMFC's Regional Mark Processing Center (Mark Center) is responsible for housing the CWT data and acknowledges that problems continue to persist in the accuracy of the data. This includes instances of fish being reported released after being recovered, mis-matched species associated with the same tag code on release and recovery records, weights out of range, and incomplete conversion to PSC data format 4.0. Nearly all of these errors relate to much earlier years (i.e. pre 1990).

On the positive side, there are over six million CWT records in the database now, with known errors on the order of a few thousand records at best. This represents less than 0.03% of the data. Errors are unacceptable, and the Mark Center is continuing its efforts to get the errors resolved.

A variety of known errors have been corrected in the past two years by working with the reporting agencies and requesting resubmission of new data files. In addition, the Mark Center has continued to add new validation tests as new types of errors come to light. But in many cases, reporting agencies have not responded to requests for data corrections and the errors have thus persisted. It is suspected that the primary reason for this is simply that the responsible data management staff are overloaded with other more pressing duties and thus can't get to the lower priority of correcting old historical CWT. It would be of great benefit to the Mark Center to have this issue elevated to a higher importance by the PSC Commissioners.

4) Mark Center Stands Ready to Assist

The Expert Panel provided a substantial number of recommendations for improving the current CWT system. As such, the Mark Center stands ready to assist the PSC in any way that it can.

Sincerely,

Randy Fisher
Executive Director

United States Department of the Interior

FISH AND WILDLIFE SERVICE
911 N.E. 11th Avenue
Portland, Oregon 97232-4181

In Reply Refer to:

AFR

DEC 16 2005

Don Kowal
Executive Secretary
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, B.C. V6E 1B5

Dear Mr. Kowal:

The Service appreciates the opportunity to comment on the Pacific Salmon Commission's "Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon" (Report), and on an earlier draft as part of the scientific peer review process. The Service commends the Pacific Salmon Commission (PSC) for addressing this important bilateral management issue and the Expert Panel for their thoughtful and thorough consideration of the fishery management system, stock assessment program, and related issues.

The Report provides a credible representation of the history, the current situation, and the future prognosis for the coded wire tag (CWT) program. Impacts to the data management system from changing fishery management strategies, ongoing needs to revise and improve stock assessment techniques, and recommendations to address these emerging fishery management framework needs are thoroughly discussed. The Service believes that the findings, recommendations, and implementation steps outlined in the Report are appropriate determinations and a reasonable approach to address the current management situation.

The west coast fishery management community needs to work in partnership to address continuing changes to fishery management strategies and new challenges resulting from the need for stock assessment evaluations at finer and finer scales. In that regard, fishery management and stock assessment techniques should continue and be expanded to: (1) accommodate a wide range of fishery management strategies, including mark selective fisheries or other alternative management strategies, where appropriate; (2) incorporate sampling techniques that are logistically feasible, well coordinated, and, where possible, do not require the sacrifice of individual fish for relevant data collection; and (3) attempt to develop evaluation protocols that integrate the unique benefits of each assessment program characteristic. The Report should serve as the launching point for this endeavor with the progression of the "Implementation Steps" section as the logical pathway to move forward. The PSC is probably the best forum to help direct this

TAKE PRIDE IN AMERICA

joint U.S./Canada effort, given it's bilateral jurisdiction, which is essential for most west coast Chinook and coho salmon stocks. The Service pledges its continued support in terms of maintaining and expanding its CWT programs if and where necessary, timely reporting of CWT release and recovery information and mass marking plans to regional data exchange centers, participation on key PSC technical committees, and serious examination of new assessment techniques that may compliment and/or replace portions of the current CWT system.

The Service strongly concurs with Recommendation 1, that we need to recommit ourselves to making improvements to the foundation of the existing CWT system, fully recognizing that problems are widespread. The CWT system has been the method of choice for fishery managers for many years, and represents a huge investment in equipment and personnel. It provides vital data for both international and domestic management programs and no major changes in approach are likely to occur in the short term (5-10 years). We should not underestimate the importance of this system and the commitment it will take to address this Recommendation.

Double Index Tagging (DIT) may provide an acceptable technical approach to issues raised by mass marking and mark-selective fisheries. The Service strongly supports Recommendation 7 to refine the DIT concept to provide metrics for better understanding when data beyond a basic CWT indicator stock program should be employed. If DIT proves technically feasible, we must recognize that coast-wide implementation will require additional planning, changes in sampling programs, data reporting, and substantial coordination and implementation costs.

The Service would be very interested in reviewing the design of a "Grand Experiment" referenced in Recommendation 8 and Implementation Step 4 to determine how we might contribute to that effort. The Service is also very interested in examining the potential benefits and costs of the newly emerging Full Parental Genotyping method for use in fisheries management of Pacific salmon fisheries (Recommendation 13). The Service now has its newly constructed genetics laboratory at the Abernathy Fish Technology Center in operational mode, which could process the genetic samples for a pilot study. The Service also believes that an expeditious transition from micro-satellite markers to Single Nucleotide Polymorphism markers makes sense to take advantage of the new technology and to capitalize on opportunities for better data standardization and sample processing cost reduction.

The Service could also investigate the possibility of participating in a coordinated study to determine the relative survival of various fin marks compared to the adipose-fin mark for fish at age two and beyond. This could be done at one or more of our National Fish Hatcheries that rear and release Chinook salmon, and have the ability to conduct otolith thermal marking techniques (Recommendation 10 and Implementation Step 3). Comparisons of fin-clip survival rate work may already have been completed with "results" residing in agency files or gray literature. This information needs to be

compiled and critically reviewed before launching a new comprehensive study effort. These types of new studies would require additional funding, but the Southern Boundary Restoration and Enhancement Fund (endowment fund) may be an appropriate source of funding.

Again, thank you for the opportunity to comment on the Report and to express our views and reconfirm our commitment towards assisting with future management needs. Please contact Dan Diggs, Assistant Regional Director of Fishery Resources, at (503) 872-2763 if you have questions or would like to discuss our comments further.

Sincerely,

Acting Regional Director

State of Washington
DEPARTMENT OF FISH AND WILDLIFE

Mailing Address: 600 Capitol Way N • Olympia, WA 98501-1091 • (360) 902-2200, TDD (360) 902-2207
Main Office Location: Natural Resources Building • 1111 Washington Street SE • Olympia, WA

December 16, 2005

Mr. Don Kowal
Executive Secretary
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, B.C., V6E 1B5

Dear Mr. Kowal:

Re: Pacific Salmon Commission Final Report of the Expert Panel regarding the Coded-Wire Tagging Program

The Washington Department of Fish and Wildlife (WDFW) has reviewed the Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon, prepared for the Pacific Salmon Commission (November, 2005). We appreciate the opportunity to provide this agency's comments on the Expert Panel's findings and recommendations, but would first like to make a few general remarks about the importance of this investigation and my expectations for the review process and potential action steps taken by the Commission and salmon managers coastwide.

This agency supported the Pacific Salmon Commission's undertaking with an expectation that the Expert Panel would address the real world salmon management challenge of how to maintain and improve the technical basis for managing our salmon resources. The data collection and management systems employed by chinook and coho salmon managers are complex, so we are not surprised that the Expert Panel required considerably more time than originally envisioned to complete its review. Although only a few weeks were provided to the agencies for review and comment on the Expert Panel's report that took more than a year to complete, we hope that our comments contribute constructively to the purpose of this project.

You will see by our comments that WDFW supports the majority of the Expert Panel recommendations. We have provided additional information where the Panel's findings appear to be based on an incomplete understanding of an issue, and we believe that some of the recommendations are not sufficiently developed to provide a basis for critique at this time (e.g., Recommendation 8 - the Grand Experiment). WDFW does not support Panel recommendations that, in our view, do not address the Panel's charge to provide practical and effective solutions to identified real world management problems.

WDFW has been a lead agency on the Pacific Coast supporting implementation of effective stock assessment programs including the coast-wide system of coded wire tagging and recovery. This agency pioneered development and applications of new stock identification technologies to address evolving management issues and associated data needs, including technologies related to mass marking and the appropriate use of selective fishing techniques. By our experience, we have demonstrated our commitment to finding practical solutions to real world challenges.

The Expert Panel's investigation was instigated at least in part by ongoing concern for the effects on the CWT system related to the introduction of mass marking and selective fisheries. As part of Finding 6, the Panel has concluded that mass marking and selective fisheries pose a serious threat to the integrity of the CWT system, underscoring that finding by including a 1991 letter to the PSC from the Chinook Technical Committee that had reached a similar conclusion. We strongly disagree with the Panel's finding and hope the Commission is able to see how far we have traveled since the CTC claim that "*removal of the adipose fin from untagged fish would destroy a long-standing program of international cooperation in the use of the CWT as an important management tool*". This finding is inconsistent with the fact that mass marking and selective fisheries have been implemented in a responsible manner for more than 10 years. It is also inconsistent with the Panel's recommendation (7) for a conceptual approach linking CWT analytical methods with the intensity of mark-selective fisheries. WDFW will continue to invest in the CWT system and explore creative alternative methods for providing the information necessary to effectively manage our salmon resources.

We concur with Commissioner Larry Rutter's charge to the Expert Panel that the practical impact of the Expert Panel's report ultimately depends on the degree that findings and recommendations are accepted and implemented by the various U.S. and Canadian management agencies. The process for actual implementation is uncertain except that it will definitely take more time. Action on many of the recommendations will require new funding, coast-wide coordination and, by the very nature of those requirements, additional time for the management community to consider the costs and benefits of investments. WDFW is committed to work with the PSC to define a process for detailed review of the recommendations for the purpose of achieving consensus or acceptance by the agencies and potential implementation of recommendations having merit. I expect the process for finding acceptance and implementing the recommendations will extend well beyond the initial deliberations on these issues during the Commission's January PSC Post Season meeting.

Sincerely,

Jeff Koenings, Ph.D.
Director

Enclosures

Washington Department of Fish & Wildlife
Review of Recommendations:
Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon

RECOMMENDATION 1. *Substantial improvements must be made in the CWT system to insure that the quality and reliability of collected data are consistent with the increasing demands being placed on these data by fishery managers. Areas requiring attention include quality control/quality assurance, and various sampling design issues including expansion of catch and escapement sampling in areas where little or no sampling currently takes place.*

WDFW acknowledges the increasing demands being placed on the CWT system in response to increasingly complex management issues confronting fishery managers. We agree with the Panel's findings that significant shortcomings exist with the CWT system with respect to the historic and future capacity to provide reliable data. In spite of these shortcomings, WDFW believes the CWT system remains a viable program and we will continue to invest in the CWT system with the intention of improving the quality of information obtained from our investments in the CWT system, at least in the short-term (at least 5+ years).

WDFW does not agree with the Panel's finding related to this recommendation (Finding 6) that mass marking and selective fisheries pose a serious threat to the integrity of the CWT system. This finding is inconsistent with the fact that mass marking and selective fisheries have been in implemented in a responsible manner, consistent with recommendations of PSC ASFEC and other technical recommendations, for more than ten years. It is also inconsistent with the Panel's Recommendation 7 for a conceptual approach linking CWT analytical methods with the intensity of mark-selective fisheries. We can only conclude that the Panel believes that mass marking and selective fishing can exist without serious threat to the integrity of the CWT system, depending on the intensity of the MM and MSF and if reasonable actions are taken to insure that basic data are collected.

As one of the agencies responsible for tagging, marking, and recovery programs, WDFW has made substantial investments to the CWT system and has acted to insure the quality and reliability of collected data by:

- Conducting new research on escapement estimation methods leading to more accurate expansion factors for escapement recoveries;
- Expanding sampling programs for CWT recovery (e.g., CWT sampling rates in Puget Sound marine sport fisheries have increased from approximately 5% prior to the advent of electronic detection sampling to 20% in recent years);
- Improving catch estimation methodologies leading to more accurate sampling expansion factors;
- Participating in coordinated technical activities on committees utilizing CWT information (SFEC, CTC and CoTC);

- Conducting biometric reviews of tagging and sampling programs at hatcheries and in fisheries (e.g., DIT program review);
- Reforming hatchery practices to improve representation of CWT release groups as natural stock indicators.

The degree to which this or any other agency is willing to make substantial new investments in the CWT system in the future depends on the availability of alternative data systems that either augment the CWT system or replace it altogether.

RECOMMENDATION 2. *Explicit criteria should be developed for the precision of statistics to be estimated from CWT recovery data. New guidelines for CWT release group sizes and fishery and escapement sampling rates should be based on these explicit criteria.*

WDFW strongly supports this recommendation but recommends that desired levels of precision and accuracy of estimates in the future need to be defined considering the full array of stock assessment technologies, not limited to the CWT system. We caution that the prospect of reaching agreement on management criteria for estimates of interest to all coast-wide managers is daunting, especially given the fact that such criteria have not been established with more than twenty five years of CWT applications. Nevertheless, we agree that clear and explicit performance criteria are essential for evaluation of the benefits of investments in our technologies. Especially now, with alternative technologies under consideration, explicit criteria are needed to help evaluate different implementation options.

RECOMMENDATION 3. *We recommend that the utility of a decision-theoretic approach, integrating costs, benefits, and risk into a formal evaluation structure be investigated as a means of prioritizing potential improvements (e.g., measures to improve CWT data – reporting, sample design, and protocol) to the CWT system. The approach should identify the release group sizes and recovery programs required to meet the statistical criteria for CWT recovery data. Sampling programs should include all fisheries, hatcheries, and spawning ground areas where CWT exploitation rate indicator stocks are present.*

WDFW may be supportive of investigations into structured approaches to prioritization of actions taken to improve our stock assessment capabilities, but specific action described by the Panel is vague.

RECOMMENDATION 4. *We recommend completion of a comprehensive survey and statistical analysis of all relevant published and unpublished CWT studies that concerns the correspondence between exploitation patterns and rates for hatchery indicator stocks as compared to their natural counterparts. This review should also include new analysis of relevant agency-collected data that have not yet been previously subject to analysis. Recommendations for additional studies should be made if they are judged necessary.*

WDFW supports this recommendation and concludes that studies to address this Panel finding would be undertaken consistent with Recommendation 9 and Recommendation 10.

> ***RECOMMENDATION 5.*** *Evaluate the utility of band-recovery or state space modeling approaches to estimate exploitation rates and maturation probabilities from cohort reconstructions based on CTW recovery data. These alternative modeling schemes may allow information from multiple cohorts to be combined to improve estimators compared to current single-cohort methods for which each cohort is treated indepenently.*

WDFW recommends that evaluation of alternate methods for CWT analysis, such as those suggested by the Panel, would be an appropriate task for the PSC's Chinook and Coho Technical Committees with input from the SFEC-AWG, *if* the PSC considers this activity has a reasonable prospect of solving problems identified by the Panel related to the CWT system. It is unclear from the Panel's report how such alternative methods will provide improvement to current methods used to estimate exploitation rates that are straightforward, understandable, and only rely on assumptions necessary to make estimation problems tractable.

Limited and preliminary comments specific to the two alternative model approaches presented by the Panel include:
Band-recovery models- The Brownie model described is under-parameterized. Current management needs would dictate that the harvest rate parameters (f's) should vary within a year from age to age. However, by increasing the number of parameters to the appropriate amount, the model will be over-parameterized and not tractable.
State-space models- Application of this modeling approach seemed to be unfinished or lacked sufficient description for managers or scientists to appreciate the potential utility.

> ***RECOMMENDATION 6.*** *To provide greater assurance that stock conservation objectives will be achieved, future fishery management regimes should compensate for increased uncertainty of fishery impacts on unmarked natural stocks due to degradation of the CWT system and non-landed mortality impacts related to MM and MSFs.*

WDFW agrees with the concept that uncertainty and risk should be considered in the design and specification of management objectives, including limits on the rates of total fishery related exploitation. As an example of this concept in application, WDFW and the Northwest Tribes incorporated risks associated with management and estimation error in the development of ceiling exploitation rates for our Puget Sound Chinook harvest management plan. We are concerned that the Panel's recommendation addresses only the relative increase in uncertainty associated with mass marking and selective fisheries, particularly given the Panel's findings related to substantial problems with CWT estimation unrelated to mass marking or mark-selective fishing (e.g., Finding 2: inaccurate or non-existent estimates of freshwater escapement, and inadequate sampling of some fisheries).

RECOMMENDATION 7. *The Panel has conducted a preliminary evaluation of a number of potential enhancements to the basic CWT system and analytical methods that address the complexities introduced by MM and MSFs. This evaluation indicates that no single solution will provide precise and accurate estimates of the stock-specific mortality of unmarked fish over all types of MSFs. Instead, we recommend an approach in which marking, tagging, and analytical methods are linked to the anticipated intensity of mark-selective fisheries.*

WDFW agrees with this recommendation and considers the concept of a categorical or threshold level approach to be a practical means of addressing problems associated with estimation of fishery impacts using CWT or other systems. We support the development of a framework for addressing the effects of bias in exploitation rate estimates on unmarked fish based on the intensity of the fishery.

Substantial staff time has been expended investigating the possibility that "*intensive MSF could have devastating impact on the long-term viability of CWT tag recovery programs*". Our analyses indicate that mark-selective fisheries actually implemented for chinook and coho salmon represent only a small total exploitation rate, and we have concluded that the impacts to the CWT system are negligible. For example, all mark-selective fisheries implemented in 2005-06 combined are projected to have a total exploitation rate of less than 5% on any individual Puget Sound natural chinook stock. Although this agency continues to advocate for expanded use of selective fisheries as a means of increasing access to hatchery produced fish, given constraints on total exploitation rates for Puget Sound chinook and Columbia River chinook stocks listed under the Endangered Species Act, WDFW does not envision a significant increase in the total exploitation rate on these stocks in mark-selective fisheries in the foreseeable future (e.g., total exploitation rates < 10% over next 5+ years). We believe the intensity level of selective fisheries on unmarked coho stocks is unlikely to increase in future years and all analyses to date have indicated undetectable or nearly undetectable impacts. Therefore, we support the imputation of non-landed mortality impacts using assumed values for non-landed mortality rates and estimating exploitation rates for marked fish based on cohort reconstruction methods applied to a single CWT release group.

RECOMMENDATION 8. *The PSC should explore the interest of fishery agencies in participating in a Grand Experiment to improve the basis for harvest management decisions coast-wide through an intensive program conducted over a short period of time. If interest is sufficient, the PSC should: (a) charge its Technical Committees (Chinook, Coho, and Selective Fishery Evaluation) with the task of preparing draft specifications for the Grand Experiment; (b) solicit proposals to assess the feasibility of conducting the experiment and develop a detailed experimental design, including cost estimates; (c) seek funding for implementation; and (d) coordinate conduct of the experiment.*

WDFW finds this recommendation lacks practical details and, especially given the likely large investment costs of the "Grand Experiment", has little interest in exploring the concept at this time.

> ***RECOMMENDATION 9.*** *The PSC and management agencies should initiate a coordinated research and implementation plan to assure application of improved technology in the management of salmon fisheries.*

WDFW supports this recommendation (see comments on Recommendation 1).

> ***RECOMMENDATION 10.*** *Additional experiments should be conducted to evaluate the use of alternative marks (e.g., a ventral fin clip or some alternative fin clip) for identification of fish bearing CWTs. Existing published information suggests that application of other external marks (e.g., a ventral fin clip) will reduce the survival of hatchery fish from release to age 2, but there is little evidence of differences in survival or behavior of externally marked versus unmarked fish past age 2. We propose some experiments that would allow, among other things, testing of a null hypothesis that survival rates for (a) AD+CWT+alternative external mark and (b) AD+CWT fish are the same from age 2 on, i.e., that there is not lingering differential mortality due to, for example, ventral fin marking.*

WDFW will support the most effective implementation strategies possible for mass marking of hatchery production, conducting selective fisheries and collecting the data necessary for stock assessment. The Panel revisited an issue that was thoroughly reviewed by the ASFEC for coho salmon in 1995 and numerous problems were identified with alternative fin marking proposals such as the ventral fin for use as the CWT identifier. WDFW has conducted comparative fin mark survival experiments in the past and would support conducting further experiments, in coordination with other agencies, if the study was carefully designed and if managers agree that the results would have a practical application. It should be clear that moving back to visible detection of CWT tagged fish does not alleviate concerns raised by the Panel related to estimation with mark-selective fisheries. Given that alternative fin marks are known to have high and variable mortality, moving away from ETD may actually add new problems in estimation. WDFW encourages further discussion on this issue.

> ***RECOMMENDATION 11.*** *We recommend that programs be developed and implemented to enhance the capacity to apply genetic methods to stock identification problems of concern to the Pacific Salmon Commission.*

WDFW has been a lead agency in the development of genetic methods applied to stock identification problems and will continue to play a lead role. We strongly support the panel's recommendation to enhance stock identification procedures and to expand baseline datasets, however, we would like to address certain shortcomings in the Panel's report on these subjects.

Coordination and Standardization of GSI Procedures

The authors of this recommendation appear to be unaware of existing programs now in effect to coordinate and standardize many of these GSI procedures. The Genetic Analysis of Pacific Salmon (GAPS) group has been tasked by the PSC to develop a standardized microsatellite baseline and scoring criteria for a range-wide Chinook database. At least nine genetic laboratories have met these scoring criteria and Version 1 of the baseline database now includes 111 Chinook populations from Asia to the Central Valley of California. More populations will be added in the first revision in early 2006.

Experience with allozymes and microsatellites has shown that standardization of genetic assays among laboratories takes work, but it is not the major obstacle to implementation of GSI methods depicted in the Expert Panel's report. The GAPS microsatellite effort has been a huge success and has shown that coordination and cooperation are possible even when labs in fierce competition are involved. It has also shown that microsatellites can be successfully standardized and are of great use in GSI.

This successful standardization of microsatellites, a highly polymorphic marker class, was achieved with targeted exchange of standards (samples), and massive sample exchanges were *not* required. For this reason, we do not support "a functional, reciprocal system for accession of tissue samples used for database construction and in fishery samples (for a reasonable, but short, period of time)." This proposed system is unnecessary (data collected in all standardized laboratories are interchangeable), unduly expensive, and impractical due to the finite and limiting amounts of material held by most laboratories. Instead, we recommend periodic and targeted exchange of standards to maintain uniformity among laboratory scoring regimes.

We believe that a management model that requires information that genetics cannot provide presents a bigger impediment to applying GSI to PSC management than does the status of standardization efforts. We agree, however that building genetic datasets capable of providing the stock resolution that managers desire will require continuing coordinated efforts involving multiple agencies and laboratories. The Pacific Salmon Commission has played a leading role in providing the focus and funding for standardized allozyme and microsatellite baselines. Additional funding will be important to expand existing baseline databases and to build new baselines using potentially more powerful genetic markers such as SNPs.

Thermal Marking

The Expert Panel provided a thorough review of thermal marking in Finding 11, including a discussion of its strengths and weaknesses as a tool for harvest management. We feel, that this marking method when combined with extant Genetic Stock Identification techniques and strontium marking by immersion can be used for coast-wide management of pacific salmon. The positive aspects associated with thermal marking include the capacity to mark 100% of the fish produced by a hatchery without individually handling them. The ability to mark every individual greatly reduces the sample sizes needed to estimate the proportions of hatchery-origin fish caught in specific fisheries. For example, estimates that are ± 5% of a true proportion can be obtained with 400 fish and often less depending upon the proportion of hatchery fish present. Moreover,

as the Expert Panel related, this method is currently used to mass mark slightly more than 20% (over 1 billion) of the hatchery salmon released into the north Pacific every year. Consequently the technique is widely known and used by countries surrounding the Pacific Rim.

Identified shortcomings included lack of infrastructure in many hatcheries to induce thermal codes, international coordination and documentation of thermal codes, potential errors in decoding thermal patterns, and the small number of potential codes that may be available. We feel that the Panel did not fully address possible solutions for the shortcomings that they identified.

First, existing water heating and chilling technology has made it possible for a hatchery to have the capacity to produce over 100 gallons per minute of 3 to 4°C chilled water for an initial investment of $45,000 U.S. This capital investment would allow a facility to mark millions of fish per year for a decade or more. Consequently, annual costs for power or fuel, and routine maintenance would represent the total marking cost for each hatchery once a water temperature system had been installed.

Second, the North Pacific Anadromous Fish Commission is currently leading an effort to document and coordinate the thermal codes placed on hatchery salmon produced from facilities located in South Korea, Japan, Russia, Canada, and the U.S. As a result, an existing database for recording the thermal codes used each year is available and could be expanded to cover future marking endeavors.

Third, errors in decoding thermal marks may occur if codes have similarities to natural patterns or if the signal to noise ratio is not adequate when marks are applied. As will be shown below, however, the incorporation of a band or bands of strontium into a code matrix would eliminate the possibility that natural–origin recruits (NORs) are misidentified as thermally marked fish. Moreover, it is has been our experience that most decoding errors occur when information is inserted into a database. When two people independently read each otolith and merge their databases the occurrence of keyboarding mistakes is greatly reduced.

The Expert Panel felt that the most significant shortcoming of thermal marking was an apparent lack of potential codes that could be applied. Systematic approaches have been developed to produce thermal codes and a brief description of these approaches is presented as an attachment (Attachment I) to this document.

Using thermal and strontium marking procedures would also allow managers to validate the age assignments made on hatchery-origin fish by scales, external otolith patterns, spines, centra, and other structures. By inference, the accuracy of age assignments given to NORs could also be estimated. This would be accomplished by producing codes that provide readers with the broodyear the fish were produced from—a standard feature in the thermal marks produced by WDFW.

Finally, it seems to us that current GSI methods could be linked to the marking methods described above to create an accurate way to estimate the contribution of NORs and hatchery fish to fisheries. Current GSI methods are very capable of identifying the stock origin of sampled fish. A combined thermal/strontium mark would identify the origin of any sampled hatchery fish. The technology to carry out such a program currently exists. In conclusion, we recommend that ideas expressed here be explored in greater detail to assess the practicality of using a hierarchy of identification methods to resolve on-going harvest management issues that currently exist in Pacific Rim salmon stocks.

Reliability of Scale Aging

As a final comment related to Recommendation 11, WDFW has a very different view of the capability to provide information on age or brood year contributions from data sources other than CWT. Many of our stock specific, cohort reconstruction data bases rely on age assignments based on scale reading so we were concerned with the Panel's conclusion regarding reliability of scale reading to age chinook and coho (Finding 14). Our interpretation of published and unpublished studies conducted to evaluate reliability of these methods appears to be just the opposite of the Expert Panel. Results of blind testing with trained scale analysts shows accuracy rates over 90%, and even freshwater fishery samples were aged with a high degree of success. The Expert Panel's conclusion that aging errors can be substantial in "*mixed stock ocean fisheries*" is confusing given the comment that "*these errors are largely attributable to scale resorption*" that occurs in freshwater. We request the Panel provide a more substantial and logical basis for their finding.

> ***RECOMMENDATION 12.*** *We recommend that the Pacific Salmon Commission support an immediate evaluation of a coordinated transition for all salmon species from genetic stock identification (GSI) based on the use of microsatellite markers to GSI based on single nucleotide polymorphism (SNPs) markers. It is important to develop standard sets of species-specific SNPs and related protocols now, so that coast-wide implementation of SNP-based GSI will be cost-effective and efficient. The best approach to such a transition is for a multi-jurisdictional agency, such as the PSC, to coordinate broad, multi-agency collaborations such as those adopted during the development of the coast-wide allozyme data bases during the last decade or during the development of the CTC standardized Chinook microsatellite data base developed over the last two years. Such collaborative efforts should include provisions for future tissue sample availability from all stocks included, so as to provide for periodic improvement and expansion of the databases.*

WDFW supports the development and inclusion of SNP markers in coast-wide and pan-Pacific genetic datasets. Nevertheless, the recommendation to transition away from (and to eliminate) microsatellites as a PSC-supported GSI tool is pre-mature, especially before we have had an opportunity to evaluate the power of a functional, range-wide SNP dataset for any salmonid species. We disagree with the Expert Panel that the human genetics community has moved away from microsatellites and into SNPs. SNPs have indeed gained prominence in some applications like human linkage mapping, but of

particular relevance here, the human forensic community has *not* switched from microsatellites to SNPs. In fact, the human forensic applications are much more similar to the stock identification and mixture analysis methods that are important to salmon management than are the linkage mapping applications, and microsatellites continue to serve well the human forensic community.

As we have discussed above, microsatellite standardization among genetic laboratories is not intractable, as implied in Recommendation 12. Again, we point to the success of the GAPS standardization effort for Chinook as an example that the scoring of microsatellites can be replicated among laboratories. The GAPS group has identified a much more practical approach to implement SNPs than what was outlined in Recommendation 12: to expand the current microsatellite dataset to include SNP loci. Most of the collaborating labs in GAPS are enthusiastic about the potential utility of SNPs for Pacific salmon GSI, but many of us believe that the microsatellite baseline that is in place should not be discarded simply because SNPs are attractive markers. As we add SNP loci to the baseline, power analyses, analyses of error rates, and relative cost efficiencies will determine the winners and losers among the loci.

> ***RECOMMENDATION 13.*** *We recommend support of a "proof-of-concept" empirical validation of the Full Parental Genotyping (FPG) method for use in management of Pacific salmon fisheries. This validation should occur in Chinook salmon and should include support for further SNP development, a series of paired CWT and FPG tag recovery experiments, as well as thorough evaluation of relative costs of implementing these methods and the sampling necessary to provide equivalent tag recovery data.*

WDFW does not support investment in a "proof-of-concept" empirical validation of the FPG method at this time. The Panel's report does not provide nearly enough information to evaluate the practicality of replacing CWT with FPG. No simulation results are presented to support the claim that 100 SNPs would be sufficient to actually accomplish the goals of FPG. We, along with many prominent Pacific salmon population geneticists, are skeptical that 100 SNPs would be sufficient. The proponents of FPG need to present their work so that we can examine their model and its underlying assumptions, paramount of which are assumptions about the geographic distribution of polymorphism among the SNP loci and independence of the loci. It might be the case that 100 SNP loci with ideal properties would be sufficient for FPG, but what proportion of SNP loci have these qualities? How do deviations from idealness affect the power for this application? These are two of the many questions that need to be addressed before we would support a commitment to FPG. We urge the proponents of this alternative to present the supporting theory, assumptions, simulations, and analyses so that the population genetics community can evaluate them.

Parentage analyses are more-or-less routine applications of microsatellite markers so the conceptual basis to FPG is well accepted. The big question about FPG centers on the scale of the application. A "proof of concept" empirical evaluation of FPG would need to test the practicality of parentage analyses when tens or hundreds of thousands of potential parents are involved. Such an evaluation would initially require at least a doubling of the number of

SNP loci that currently are available and likely would divert an enormous amount of funding away from initiatives with immediate application and benefit to PSC.

> ***RECOMMENDATION 14.*** *We recommend that a feasibility study be conducted to determine how PIT, RFID or other electronic tags might be applied to generate data suitable for full cohort reconstruction.*

WDFW supports employment of electronic tag methods but considers this alternative technology to have a lower priority than other approaches, particularly given limited funding for studies.

> ***RECOMMENDATION 15.*** *PSC technical committees should explore potential fishery management regimes that would rely less on estimates of age-fishery-specific exploitation (or non-landed mortality) rates, but that would still ensure adequate protection for unmarked natural stocks of concern.*

WDFW strongly supports a coordinated, coast-wide effort to explore future fishery management regimes that are more realistic with respect to capabilities of data collection, while providing necessary protection for natural stocks. We understand the challenge presented to the coast-wide management community by the call for significant change to existing regimes, but the Panel's findings identifying significant shortcomings to stock assessment capabilities underlying the current PSC regimes for chinook and coho, coupled with reduced funding to agencies responsible for implementing these programs, present a compelling set of circumstances to consider modification of our current management structures.

Attachment I
Systematic Approaches to Produce Thermal Otolith Codes

One of the first and most versatile is the interleaved 2 or 5 rule developed by Volk et al (1994). In this code, six thermal events are used to create five spaces, two of which are twice as wide as the remaining three (Fig 1). Ten possible bar codes can be produced by this method. Although this code has been prominently used by WDFW to produce thermal marks, nothing prevents us from using 1, 3, 4, 5 or no wide spaces in a six thermal event pattern. When this is done, 32 possible codes can be produced. Immersing alevins or fry into baths containing stable strontium can create additional codes. For example, Schroder et al. (1995) and Schroder et al. (1996) reported that highly visible bands of strontium are incorporated into the otoliths of alevins, fry, fingerlings and smolts after they had been immersed in a strontium chloride solution for several hours. Fig 2 shows BEI images (backscattered electron

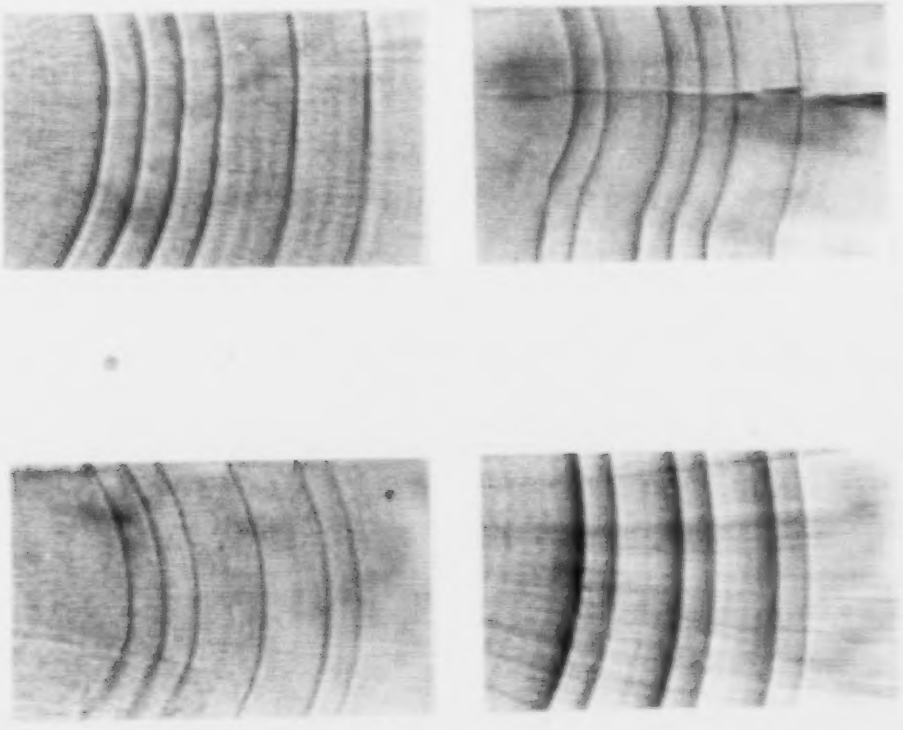


Fig 1. Examples of the "bar code" patterns that can be produced by using the interleaved 2 of 5 rule. The upper left-most image represents the Narrow Narrow Narrow Wide Wide option for this code. There is enough space on a typical salmonid otolith to induce three sets of these patterns providing 1000 potential codes.

images) of otoliths that were collected from salmonid alevins exposed to strontium marking waters. Each intense white band illustrates deposited strontium. The incorporation of a strontium band into a thermal code matrix greatly expands the number of codes that can be applied to hatchery salmon (Table 1). For example if we incorporated two strontium marks, one in the second and one in the third set of 5 bands over 800,000 potential marks are possible. A BEI image of an otolith with a thermal mark and strontium mark is shown in Fig 3.

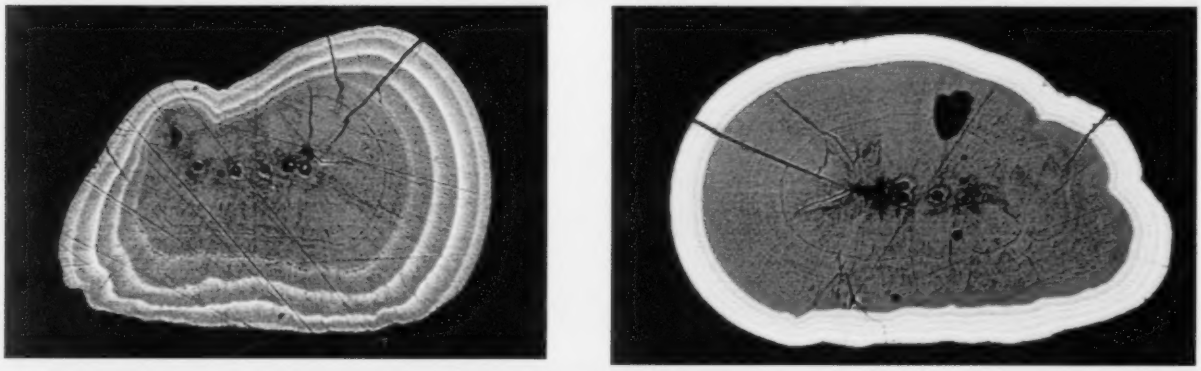


Fig 2. Backscattered Electron Images of otoliths removed from salmon alevins exposed to 1000 ppm strontium chloride hexahydrate solutions. The left-hand otolith was exposed to the solution for 4 hrs with a five-day interval between marking events while the fish producing the right-hand specimen was held for 24 hrs with two-day intervals between marking events.

Table 1. The potential marks that can be produced by combining thermal marking with strontium immersion marking. Strontium bands would be induced within a space defined by two thermal events to produce each pattern. If a single strontium immersion event occurred in post-hatch zones 1 and 2 then there would be 32x160x160 or 819,200 possible codes.

Mark Pattern		Pre-Hatch	Post-Hatch Zone 1		Post Hatch Zone 2	
# Of Wide Spaces	# Of Narrow Spaces	No Of Possible Patterns	No Of Possible Patterns		No Of Possible Patterns	
			No Sr Mark	With Sr Mark	No Sr Mark	With Sr Mark
0	5	1	1	5	1	5
1	4	5	5	25	5	25
2	3	10	10	50	10	50
3	2	10	10	50	10	50
4	1	5	5	25	5	25
5	0	1	1	5	1	5
TOTALS		32	32	160	32	160

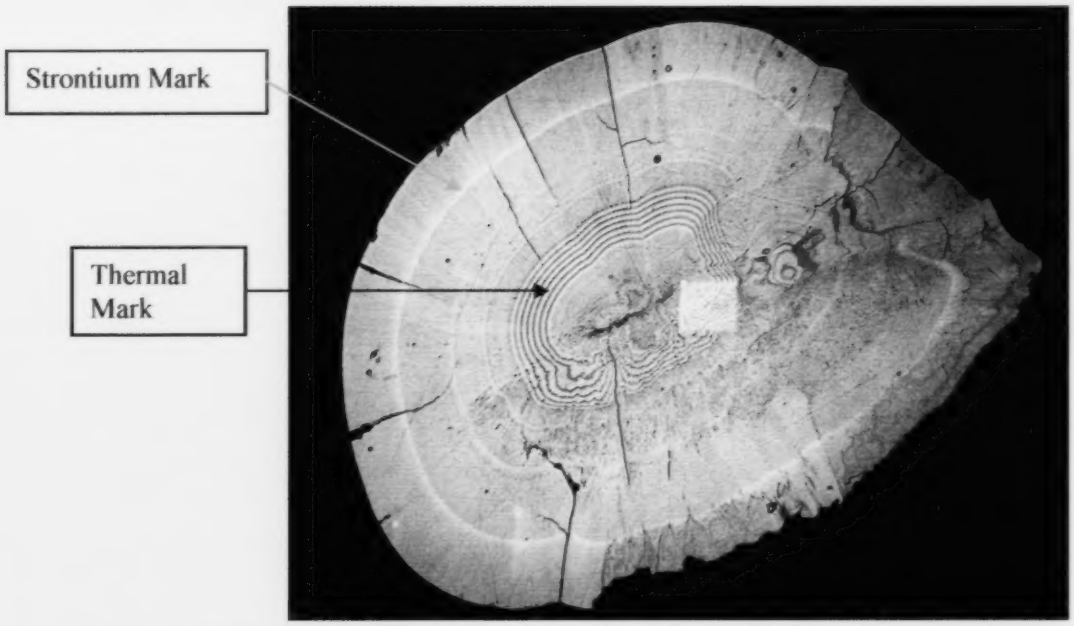


Fig. 3. A BEI image of a thermally marked otolith that also possessed a strontium mark.

Strontium marking would be accomplished by re-circulating marking waters through the incubation devices used to house alevins. Systems that re-circulate strontium marking waters are currently in use in Washington State where they are being employed to mark newly emerged salmon that are leaving natural spawning areas. This approach allows the same marking waters to be repeatedly used to mass mark thousands of juveniles over several months. Marking waters can be safely disposed of by transporting them to local sewage treatment plants. The cost of such a mark is quite reasonable, for example, $50 of strontium chloride hexahydrate crystals can be used to produce about 400 gallons of marking solution, enough to mark millions of fry in a hatchery setting.

A variety of techniques can be used to detect strontium marks. Using a Scanning Electron Microscope for example creates BEI images like those displayed in Figures 2 and 3 and allows their placement within a thermal code to be discerned. Wave Dispersive Spectrometry (WDS), Laser-Ablation Inductively Coupled Mass Spectrometry (LA-ICPMS) and other microprobe methods can also detect strontium marks. A laser track across an otolith section is depicted in Fig. 4. In this type of analysis, strontium marks would show up as peaks of anomalously high concentrations of strontium, anywhere

from 5 to 10 times greater than background levels. Thermal marks are detected by creating polished hemi-sections and then examining them under a dissecting scope. A similar approach is used for strontium marks except in this instance the specimens are coated with thin layer of carbon before being analyzed. Cost per adult otolith would range between 12 to $20 depending on machine (e.g. LA ICPMS) costs.

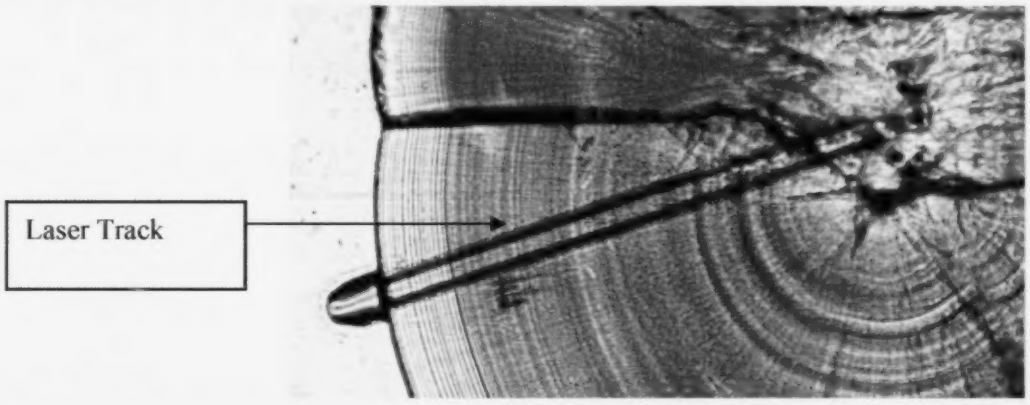


Fig 4. A photomicrograph showing a laser track across one half of an otolith hemi-section.

Literature Cited

Schroder, S.L., C.M. Knudsen, and E.C. Volk 1995. Marking salmon fry with strontium chloride solutions. Can. J. Fish. Aquat. Sci. 52:1141-1149.

Schroder, S.L., E.C. Volk, C.Knudsen, and J.J. Grimm. 1996 Marking embryonic and newly emerged salmonids by thermal events and rapid immersion in alkaline-earth salts. Bull. Natl. Res. Inst. Aquacult., Suppl. 2: 79-83.

Volk, E.C., S.L. Schroder, J.J. Grimm, and S. Ackley. 1994. Use of a bar code symbology to produce multiple thermally induced otolith marks. Trans. Am. Fish. Soc. 123:811-816.